The American Bald Cypress

(Taxodium distichum, Rich.)

ITS PHYSICAL AND CHEMICAL PROPERTIES
WITH SPECIAL REFERENCE TO RED CYPRESS—COAST TYPE

BY
HERMANN VON SCHRENK

Published by the Southern Cypress Manufacturers' Association
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Contents

I. INTRODUCTION

In view of the fact that many different species of wood are available for different purposes, it is becoming increasingly important that there should be a proper understanding on the part of the user of the physical and chemical characteristics of wood so as to make an intelligent choice. In the following pages some of the more important qualities of cypress wood are discussed, with the presentation of tables and charts giving data not only as to cypress but for other woods which might be considered in connection with any particular item of use. While extensive quotations are given from authoritative sources, it will always be advisable to consult the original volumes or papers cited.

Cypress

Cypress lumber is manufactured from the American Bald Cypress (Taxodium distichum) growing in low swamp-lands along the Atlantic Coast, from Virginia to Florida, westward along the Gulf of Mexico to Texas, and up the Mississippi Valley as far as Missouri. The wood is variously known as red, black, white and yellow cypress.

The United States Department of Commerce in its standardization program for lumber, as outlined in Simplified Practice Recommendation, Lumber, R. 16-29, p. 27, has assigned to the various types of cypress the following standard commercial names to be used in the construction of contracts and in the formulation of lumber-grading rules and the terms of purchase and sale of American Standard Lumber.

Standard Commercial Name	*Botanical Name*
Red Cypress (coast type)	Taxodium distichum
Yellow Cypress (Inland type)	Taxodium distichum
White Cypress (Inland type)	Taxodium distichum

Cypress grown in the deep swamps of the coastal plain regions near tidewater is now commercially called Tidewater Red Cypress to distinguish it from the inland, or upland cypresses, which are lighter in color and not as durable.

Cypress heartwood is variable in color. The Tidewater Cypress (that is the cypress close to salt water) will vary from slightly reddish to a deeper red and much of it will be almost black with intermediate gradations. Away from the salt water, the heartwood is usually slightly reddish or even lighter in color.

Cypress heartwood is one of, if not the most durable kind of lumber manufactured in the United States. "The great durability of the heartwood, probably more than any other property, gives cypress the place of distinction which it holds among the more valuable woods on the market."*

"In respect to strength, cypress holds a position intermediate between that of the white and the heavy yellow pines."*

"The wood varies in weight usually from 22 to 37 pounds, averaging about 28 pounds per cubic foot, when thoroughly air-dried."*

"Cypress has a great variety of uses, and for many of these it is selected as a preferred material. The key to its usefulness is its resistance to decay and other forms of deterioration when in contact with moisture, and its quality of being easily worked. It is used extensively for outside finish of buildings, such as siding, casing, sashes, doors and blinds, cornice, railings, steps and porch material. As a gutter stock, cypress outlasts many other materials and is in favor for high-grade work. Standard planing products consume large quantities of cypress. These include ceiling, siding, flooring, moulding, and finish. On account of its freedom from taste and great durability, it is preferred material for tanks, vats, tubs and wooden buckets. These are used for water storage and by creameries, breweries, bakeries, dye works, distillieries, and soap and starch factories. In the construction of greenhouses where wood is subjected to extremes of heat and moisture, cypress is used probably more than any other wood."*

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*Southern Cypress, by Wilbur R. Mattoon, U. S. Dept. of Agriculture Bulletin No. 272, September, 1915.

II. LASTING POWER OF CYPRESS

One of the outstanding characteristics of cypress wood is its lasting power. Many species of wood will decay more or less rapidly when exposed to conditions favoring the growth and development of fungi which cause decay. The fungi causing decay require the following for active growth:—a food supply, water, heat and oxygen. The absence of one or more of these conditions will prevent decay. For instance, wood will not decay, if it is kept continuously dry. Neither will it decay if kept continuously wet or submerged under water; nor will it decay in the absence of

oxygen, for example, when buried deep in the ground. Ideal conditions for decay are found in humid climates and under conditions similar to those found in such climates. Wood in contact with the ground where there is plenty of moisture, sufficient air and sufficient heat, is in an ideal situation conductive to rapid decay. The same is true of wood kept in confined spaces. It is on this account that rapid decay may be anticipated in cellars, porches, cold storage rooms, ice houses, greenhouses, foundation timber, stock pens, hog houses and incubators, etc.

There is a marked difference in the tendency to decay in sapwood (the lighter colored and outer portion of the tree) and heartwood, of different species of trees. The sapwood of practically all trees both in the temperate and tropical regions is liable to decay very rapidly, in fact there is very little difference in the lasting power of sapwood no matter what tree it comes from. Heartwood, on the other hand, may decay very rapidly, or may be very resistant to decay. The heartwood of some species is very long-lived, while the heartwood of others may be very short-lived. Species of heartwood with short life are such species as the true firs, spruces, sycamore, red oak, etc. The heartwood of cedars, cypress, redwood, osage orange and catalpa are examples of species having great resistance to decay. The gist of the foregoing is that when long life is expected of natural wood, care should be taken to exclude the sapwood and consider the heartwood only.

There has been a good deal of speculation as to why the heartwood of trees like cypress has such strong decay-resistant properties. In all probability, there are certain natural preservatives which are formed in the development of the heartwood. Some investigators have ascribed this decay resistance to resins or derivatives of resins. Some years ago, the writer prepared a resin-like compound from the heartwood of cypress, which later on was studied with much care by Dr. A. F. Odell* who gave the name "Cypressene" to this compound.

He found that this substance was a sesquiterpene (very similar to cadinene found in European cypress). This substance resinifies easily. Dr. Odell calls attention to the fact that in the very slow-growing coast cypress the bands of summer wood are close together. The resin containing cells occur largely in the summer wood and there is hence a very uniform distribution of resin throughout the wood mass. In view of the fact that the sesquiterpene is part of the resin, the uniform distribution of this important element is accordingly attained in the close grained wood. Then he goes on to say "The very condition which is most calculated to make ordinary wood rot quickest is the very condition which seems to preserve cypress the best, *i. e.*, alternate exposure to dampness and air. This alternate exposure is necessary for developing resinification of sesquiterpene which hardened by oxidation literally coats the cell walls of the wood with impervious varnish, keeping the cellulose structure itself intact from the action of the elements."

Hawley and Wise† in discussing the natural durability of wood say:

"Except for the extraneous materials there is not sufficient difference in the chemical composition of various species or of heart and sap to account for these differences in resistance to decay, so that the differences in durability, of heart and sap at least, have been ascribed to the extractives. It has commonly been assumed that the presence of certain soluble and easily assimilated substances in the sapwood such as 'sugars, starches, gums, etc.' acted as promoters or accelerators of decay by furnishing a ready food for the fungus while the absence of such substances in the heartwood made it difficult for the fungus to get a start. Such a theory, however, failed to account for the fact that in certain species of wood the heartwood decayed almost as readily as the sapwood."

These authors then refer to a number of investigations dealing with extractives and stated briefly:

"It was found that the hot-water extract was always more toxic than the cold-water extract and that the heartwood extracts were always more toxic than the sapwood extracts. In general the toxicity of the extracts was about what would be expected from the durability of the wood, although there are no figures for natural durability from which accurate comparisons could be made."

This conclusion will probably hold generally, but as indicated also by Hawley and Wise, it will not hold in the case of the oaks, because extractions of red and white oak show equal toxicity, whereas it is a well-known fact that white oak heartwood is very resistant to decay, whereas red oak heartwood decays very rapidly. The mechanism of decay protection for long-lived woods is therefore still to be determined. At the present time, one can only say, that based on many years of experience, the heartwood of cypress, cedar, redwood and others, is ex-

*"A Sesquiterpene and an olefinic camphor occurring in Southern Cypress," by Allan F. Odell, Journal American Chem. Soc. 33:755-8, 1911.

†"The Chemistry of Wood," by L. F. Hawley and Louis E. Wise, 1926, pp. 304-307.

tremely decay resistant, even under the most favorable conditions for bringing about decay. The following table prepared by Koehler* will be found useful:

TABLE 1.

Relative Durability of the Heartwood of Common Woods

Conifers	*Hardwoods*
Very Durable	
Cedar, northern white Port Orford Red (pencil cedar) Western red Cypress Redwood	Catalpa Chestnut Locust, black Mulberry Osage orange Walnut, black
Durable	
Fir, Douglas Larch, eastern (tamarack) Western Pine, longleaf Eastern white	Cherry, black Locust, honey Oaks, white
Intermediate	
Pine, loblolly Norway Shortleaf Sugar Western white	Ash, white Butternut Elm, red White Gum, red Oaks, red Poplar, yellow
Non-durable	
Firs, true Hemlock, eastern Western Pine, western yellow Spruces	Aspen Basswood Beech Birch Box elder Buckeye Cottonwood Hickory Maple, hard Soft Sycamore Tupelo Willow

Referring specifically to the heartwood of cypress, its great durability is very well known. Wilbur R. Mattoon, Forest Examiner, very well states the case in the following paragraph:†

"The great durability of the heartwood, probably more than any other property, gives cypress the place of distinction which it holds among the more valuable woods on the market. In contact with the soil or exposed freely to water or atmospheric conditions, the heartwood ordinarily resists for many years the agencies of decay, while the sapwood under similar conditions is comparatively short-lived. Instances of cypress shingles lasting 50 to 100 years, fences in good condition after 40 years, old plantation buildings in the warm, humid Southern States in excellent preservation after 100 to 200 years and others of a like character are frequently reported."

In referring to the great durability of cypress, it should be remembered that this is not true of all cypress, indiscriminately. The longest-lived cypress wood (as has already been indicated) is that which is cut from trees which grow fairly close to salt water and which is generally known as Red Cypress—Coast Type, Tidewater Red Cypress, also as Tidewater Cypress, Red Cypress, etc. The inland cypress (known also as yellow or white cypress) is a much more rapidly growing tree. It is also characterized by a greater relative percentage of sapwood. The inland cypress also has a lower average weight per cubic foot than the coast type. Whatever may be the explanation for the decay resistance of the heartwood of cypress, experience has abundantly shown that the maximum length of life is to be anticipated from wood which is cut from slow growing darker colored trunks of trees which grow near tide water.

Pecky cypress is the name applied to the heartwood of a great deal of cypress which is characterized by the presence of numerous holes or grooves when sawed into boards, usually filled with yellowish mass of powder or fibres. The wood looks badly decayed and at first sight would be rejected as unfit. The peculiar holes in this wood are caused by a fungus (Fomes geotropus, Cooke) which grows in the heartwood of living trees.‡ The wood surrounding the holes is perfectly firm and solid. Experiences of many years have shown that pecky cypress wood possesses the same decay resistant properties as the heartwood of cypress without the holes. It is for this reason that pecky cypress has found such extensive application for a great many uses, when strength is a secondary factor, or when the pecky wood is strong enough for the particular purposes. Among the items of use mentioned, railroad ties, posts, greenhouse uses, siding, etc. In recent years, pecky cypress has been extensively used for interior finish because of its unusual appearance and decorative effect. It is used in the exteriors of the English type or half timber house.

*Properties and Uses of Wood, by Arthur Koehler, 1924, p. 224.
†Southern Cypress, Bulletin No. 272, U. S. Dept. of Agri., 1915, p. 9.
‡A disease of Taxodium known as Peckiness, etc., by Hermann von Schrenk, 11th Report Mo. Botanical Garden, 1899.

III. WEIGHT AND STRENGTH OF CYPRESS

CYPRESS is one of the lighter woods. It will vary in specific gravity from .35 to .58. The coast cypress will have an average specific gravity when green of .41 and .47 when oven dry. In terms of weight per cubic foot, the average will be about 48 pounds when green and 34 pounds when air dried and 33 pounds when kiln dried. These figures should of course be considered as average because naturally weight will depend a good deal upon the type of tree from which the timber is cut. In strength, cypress is intermediate between the white and southern pines. The following table (No. 2) showing working stresses for select and common grades of timber, developed by the United States Forest Products Laboratory, gives a comparison between the various woods including southern cypress which will be found useful.

Table 2.—WORKING STRESSES FOR SELECT AND COMMON GRADES OF TIMBER CONFORMING TO AMERICAN LUMBER STANDARDS BASIC PROVISIONS FOR STRUCTURAL MATERIAL[1]

(As recommended by the U. S. Forest Products Laboratory)

Species	Fiber stress in bending[2]										Compression perpendicular to grain			Horizontal shear[3]		Compression parallel to grain (Short columns having ratio of length to least dimension of 11 or less)						Average modulus of elasticity[4]
	Continuously dry		Occasionally wet but quickly dried				More or less continuously damp or wet				Continuously dry	Occasionally wet but quickly dried	More or less continuously damp or wet	Not varied with conditions of exposure		Continuously dry		Occasionally wet but quickly dried		More or less continuously damp or wet		Not varied with conditions of exposure or with grade
	All thicknesses		Material 4 in. and thinner		Material 5 in. and thicker		Material 4 in. and thinner		Material 5 in. and thicker													
	Select grade	Common grade	Select grade	Common grade	Select grade	Common grade	Select grade	Common grade	Select grade	Common grade	Select and common grades			Select grade	Common grade	Select grade	Common grade	Select grade	Common grade	Select grade	Common grade	
	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.	Lbs. per sq. in.
Ash, black	1,000	800	800	680	900	720	710	600	800	640	300	200	150	90	72	650	520	550	440	500	400	1,100,000
Ash, commercial white	1,400	1,120	1,070	910	1,200	960	890	760	1,000	800	500	375	300	125	100	1,100	880	1,000	800	900	720	1,500,000
Aspen and largetooth aspen	800	640	580	490	650	520	440	370	500	400	150	125	100	80	64	700	560	550	440	450	360	900,000
Basswood	800	640	580	490	650	520	440	370	500	400	150	125	100	80	64	700	560	550	440	450	360	900,000
Beech	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800	500	375	300	125	100	1,200	960	1,100	880	900	720	1,600,000
Birch, paper	900	720	670	570	750	600	530	450	600	480	200	150	100	80	64	650	520	550	440	450	360	1,000,000
Birch, yellow and sweet	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800	500	375	300	125	100	1,200	960	1,100	880	900	720	1,600,000
Cedar, Alaska	1,100	880	890	760	1,000	800	800	680	900	720	250	200	150	90	72	800	640	750	600	650	520	1,200,000
Cedar, western red	900	720	710	600	800	640	670	570	750	600	200	150	125	80	64	700	560	700	560	650	520	1,000,000
Cedar, northern and southern white	750	600	580	490	650	520	530	450	600	480	175	140	100	70	56	550	440	500	400	450	360	800,000
Cedar, Port Orford	1,100	880	890	760	1,000	800	800	680	900	720	250	200	150	90	72	900	720	825	660	750	600	1,200,000
Chestnut	950	760	760	650	850	680	620	530	700	560	300	200	150	90	72	800	640	700	560	600	480	1,000,000
Cottonwood, eastern and black	800	640	580	490	650	520	530	450	600	480	150	125	100	80	64	700	560	550	440	450	360	900,000
Cypress, southern	1,300	1,040	980	830	1,100	880	800	680	900	720	300	225	200	100	80	1,100	880	1,000	800	800	640	1,200,000
Douglas fir (western Washington and Oregon type)[6]	1,600	1,200	1,233	983	1,387	1,040	948	756	1,067	800	[5]347	[5]240	[5]213	90	72	1,173	880	1,067	800	907	680	1,600,000
Douglas fir (dense)[6]	1,750	1,400	1,349	1,147	1,517	1,213	1,037	882	1,167	933	379	262	233	105	84	1,283	1,027	1,167	933	992	793	1,600,000
Douglas fir (Rocky Mountain type)	1,100	880	800	680	900	720	620	530	700	560	275	225	200	85	68	800	640	800	640	700	560	1,200,000
Elm, rock	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800	500	375	300	125	100	1,200	960	1,100	880	900	720	1,300,000
Elm, slippery and American	1,100	880	800	680	900	720	710	600	800	640	250	175	125	100	80	800	640	750	600	650	520	1,200,000
Fir, balsam	900	720	670	570	750	600	530	450	600	480	150	125	100	70	56	700	560	600	480	500	400	1,000,000
Fir, commercial white	1,100	880	800	680	900	720	710	600	800	640	300	225	200	70	56	700	560	700	560	600	480	1,100,000
Gum, red, black, and tupelo	1,100	880	800	680	900	720	710	600	800	640	300	200	150	100	80	800	640	750	600	650	520	1,200,000
Hemlock, eastern	1,100	880	800	680	900	720	710	600	800	640	300	225	200	70	56	700	560	700	560	600	480	1,100,000
Hemlock, western	1,300	1,040	980	830	1,100	880	800	680	900	720	300	225	200	75	60	900	720	900	720	800	640	1,400,000
Hickory (true and pecan)	1,900	1,520	1,330	1,130	1,500	1,200	1,070	910	1,200	960	600	400	350	140	112	1,500	1,200	1,200	960	1,000	800	1,800,000
Larch, western	1,200	960	980	830	1,100	880	800	680	900	720	325	225	200	100	80	1,100	880	1,000	800	800	640	1,300,000
Maple, sugar and black	1,500	1,200	1,150	980	1,300	1,040	890	760	1,000	800	500	375	300	125	100	1,200	960	1,100	880	900	720	1,600,000
Maple, red and silver	1,000	800	800	680	900	720	620	530	700	560	350	250	200	100	80	800	640	700	560	600	480	1,100,000
Oak, commercial red and white	1,400	1,120	1,070	910	1,200	960	890	760	1,000	800	500	375	300	125	100	1,000	800	900	720	800	640	1,500,000
Pine, southern yellow[6]	....	1,200	....	983	....	1,040	....	756	....	800	[5].......	[5]......	[5].......	....	88	....	880	....	800	....	680	1,600,000
Pine, southern yellow (dense)[6]	1,750	1,400	1,349	1,147	1,517	1,213	1,037	882	1,167	933	379	262	233	128	103	1,283	1,027	1,167	933	992	793	1,600,000
Pine, northern white, western white, western yellow and sugar	900	720	710	600	800	640	670	570	750	600	250	150	125	85	68	750	600	750	600	650	520	1,000,000
Pine, Norway	1,100	880	890	760	1,000	800	710	600	800	640	300	175	150	85	68	800	640	800	640	700	560	1,200,000
Poplar, yellow	1,000	800	800	680	900	720	710	600	800	640	250	150	125	80	64	800	640	700	560	600	480	1,100,000
Redwood	1,200	960	890	760	1,000	800	710	600	800	640	250	150	125	70	56	1,000	800	900	720	750	600	1,200,000
Spruce, red, white, and Sitka	1,100	880	800	680	900	720	710	600	800	640	250	150	125	85	68	800	640	750	600	650	520	1,200,000
Spruce, Engelmann	750	600	580	490	650	520	440	370	500	400	175	140	100	70	56	600	480	550	440	450	360	800,000
Sycamore	1,100	880	800	680	900	720	710	600	800	640	300	200	150	80	64	800	640	750	600	650	520	1,200,000
Tamarack (eastern)	1,200	960	980	830	1,100	880	800	680	900	720	300	225	200	95	76	1,000	800	900	720	800	640	1,300,000

[1]American Lumber Standards: Basic provisions for American Lumber Standards grades are published by the U. S. Department of Commerce in Simplified Practice Recommendation R16-29, "Lumber," effective July 1, 1929; specifications for grades conforming to American Lumber Standards are published in the 1927 Standards of the American Society for Testing Materials, and in American Railway Engineering Association Bulletin, Vol. 30, No. 314, dated February, 1929.

[2]Stress in Tension: The working stresses recommended for Fiber Stress in Bending may be safely used for tension parallel to grain.

[3]Joint Details: The shearing stresses for joint details may be taken for any grades as 50 per cent greater than the horizontal shear values for the Select Grade.

[4]Factors to be Applied to Average Modulus of Elasticity Values: The values for modulus of elasticity are average for species and not safe working stresses. They may be used as given for computing average deflection of beams. When it is desired to prevent sag in beams values one-half those given should be used. In figuring safe loads for long columns values one-third those given should be used.

[5]Working Stresses for the Common Grade: The values given are for the Select Grade. Working stresses in compression perpendicular to grain for the common grades of Douglas fir (western Washington and Oregon type) and southern yellow pine are 325, 225, and 200, respectively, for continuously dry, occasionally wet but quickly dried, and more or less continuously damp or wet conditions.

[6]Exact Figures Given: In order to preserve the exact numerical relations among working stresses for grades involving rate of growth and density requirements the values for Douglas fir (western Washington and Oregon type) and for southern yellow pine have not been rounded off, as have the values for the other species.

U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
MADISON, WISCONSIN
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IV. NAIL AND SCREW-HOLDING VALUE OF WOOD

VARIOUS species of wood have different nail-holding powers. As indicated recently by L. J. Markwardt, Senior Engineer, U. S. Forest Products Laboratory.*

"The heavier woods were usually associated with higher holding power than the lighter ones, but comparative information has been lacking on this property. Nail holding is vital to innumerable uses of wood and in construction, such as in boxes and crates where the joints are frequently the weakest parts, the choice of a species may depend upon nail-holding power."

Cypress is a wood which has a high degree of nail-holding power among the conifers. It apparently has more holding power than would be expected from its weight and structure. The following table gives the nail-holding power of various species of wood as determined by the Forest Service.†

*Nail-Holding Power of Various Species of Wood, by L. J. Markwardt and J. M. Gahagan, American Lumberman, July 13th, 1929, p. 58.

†Same article by Markwardt and Gahagan above quoted.

TABLE 3—NAIL-HOLDING POWER OF VARIOUS SPECIES OF WOOD

(7d cement-coated nails driven to a depth of one and one-quarter inches and pulled at once)

Common and botanical name of species—	Place of growth of material tested	Number of trees	Moisture content *per cent*	Specific gravity base on vol. and wt. of oven-dry wood	Average holding power for one nail when driven into: End surface *pounds*	Radial surface (edge-grain) *pounds*	Tangential surface (flat-grain) *pounds*
Ash, white (*Fraxinus americana*)	Ark.	5	8.9	0.64	385	455	452
Aspen (*Populus tremuloides*)	Colo., New Mex., Wis.	..	5.3	.39	117	187	201
Aspen, largetooth (*Populus grandidentata*)	Wis.	5	6.5	.41	157	202	207
Basswood (*Tilia glabra*)	Pa.	5	6.5	.41	138	199	194
Beech (*Fagus grandifolia*)	Ind.	5	8.4	.67	358	495	460
Birch, yellow (*Betula lutea*)	Wis.	5	8.6	.66	331	473	451
Cedar, western red (*Thuja plicata*)	Mont., Wash.	10	7.6	.34	118	192	202
Cedar, northern white (*Thuja occidentalis*)	Wis.	5	9.3	.32	103	153	160
Chestnut (*Castanea dentata*)	Md., Tenn.	10	9.2	.45	172	258	273
Cottonwood, black (*Populus trichocarpa*)	Wash.	5	5.9	.37	122	194	196
Cottonwood, eastern (*Populus deltoides*)		..	6.8	.34	143	189	197
Cypress, southern (*Taxodium distichum*)	La., Mo.	10	8.3	.47	144	266	291
Douglas fir (*Pseudotsuga taxifolia*)	Oreg., Wash.	28	6.3	.51	183	273	296
Elm, American (*Ulmus americana*)	Pa.	5	8.2	.54	236	344	339
Fir, California red (*Abies magnifica*)	Calif.	3	9.0	.37	100	177	189
Fir, silver (*Abies amabilis*)	Wash.	5	4.9	.40	86	201	207
Fir, white (*Abies concolor*)	Calif.	8	8.0	.41	104	176	203
Fir, lowland white (*Abies grandis*)	Idaho	5	5.3	.36	60	150	182
Gum, red (*Liquidambar styraciflua*)	Ark.	..	8.3	.51	192	292	278
Gum, tupelo (*Nyssa aquatica*)	La., Mo.	6	9.3	.52	233	376	345
Hemlock, eastern (*Tsuga canadensis*)	Tenn., Wis.	28	8.9	.42	127	225	230
Hemlock, western (*Tsuga heterophylla*)	Wash.	9	6.7	.46	149	266	277
Hop-hornbeam (*Ostrya virginiana*)	Wis.	3	6.5	.76	457	513	480
Larch, western (*Larix occidentalis*)	Idaho	5	4.4	.58	180	299	319
Locust, black (*Robinia pseudoacacia*)	Tenn.	3	4.1	.71	404	461	345
Locust, honey (*Gleditsia triacanthos*)	Ind.	1	6.5	.76	431	508	449
Magnolia, cucumber (*Magnolia acuminata*)	Tenn.	5	5.1	.52	233	350	335
Maple, black (*Acer nigrum*)	Ind.	1	9.8	.62	357	480	415
Maple, silver (*Acer saccharinum*)	Wis.	5	6.8	.51	280	333	338
Maple, sugar (*Acer saccharum*)	Ind.	4	9.2	.65	396	497	459
Oak, red (*Quercus borealis*)	Ark., Tenn., N. H.	22	8.4	.66	312	466	422
Oak, white (*Quercus alba*)	Ark., La.	10	8.6	.72	320	496	444
Pine, jack (*Pinus banksiana*)	Wis.	5	7.6	.46	161	228	272
Pine, loblolly (*Pinus taeda*)	Fla.	10	8.0	.59	179	271	335
Pine, lodgepole (*Pinus contorta*)	Colo., Idaho	8	6.3	.44	141	244	252
Pine, longleaf (*Pinus palustris*)	Fla., La., Miss.	34	7.7	.64	244	362	376
Pine, mountain (*Pinus pungens*)	Tenn.	5	7.1	.55	209	318	330
Pine, Norway (*Pinus resinosa*)	Wis.	5	7.4	.51	165	273	282
Pine, pitch (*Pinus rigida*)	Tenn.	5	7.7	.54	235	325	330
Pine, pond (*Pinus rigida serotina*)	Fla.	5	7.5	.57	211	348	384
Pine, shortleaf (*Pinus echinata*)	La.	6	7.2	.58	235	331	377
Pine, slash (*Pinus caribea*)	Fla.	5	7.6	.68	290	356	420
Pine, northern white (*Pinus strobus*)	Wis.	5	7.7	.39	136	220	225
Pine, western white (*Pinus monticola*)	Mont.	5	8.2	.45	134	255	246
Pine, western yellow (*Pinus ponderosa*)	Calif., Oreg.	7	6.6	.44	122	224	233
Poplar, yellow (*Liriodendron tulipifera*)	Tenn.	5	7.3	.42	162	212	223
Redwood (*Sequoia sempervirens*)	Calif.	11	*6.0	.42	106	221	226
Spruce, Engelmann (*Picea engelmannii*)	Colo.	5	9.4	.36	136	177	184
Spruce, red (*Picea rubra*)	Tenn.	5	10.7	.41	148	229	221
Spruce, white (*Picea glauca*)	Wis.	5	7.6	.43	146	209	218
Sycamore (*Platanus occidentalis*)	Tenn.	5	7.0	.55	270	369	349

The nail-holding properties of wood are in general closely related to the specific gravity or density of the material but species characteristics may, however, account for variations, of as much as 25 per cent in these relations. Since in any species there is variation in specific gravity (one-half of the material falling within about 8 per cent of the average specific gravity) the nail-holding properties of individual pieces may vary considerably from the averages presented (one-half of the material falling within about 12 per cent of the average nail-holding value for the species). Hence it is possible to select material of any species that is relatively high in nail-holding properties and is better than the average.

*Approximate.

Figure No. 1‡ is a curve to illustrate the relation between the specific gravity and nail-holding power. From this curve it will be noted that cypress ranks fairly high among the soft woods, in fact it is almost equal in nail-holding power to Douglas fir.

What has been said of the nail-holding power applies equally well to the holding power of wood screws. An exhaustive investigation of this subject was made several years ago by the U. S. Bureau of Standards.§ The holding power of various types of screws was tested with the following typical woods: yellow poplar, cypress, Georgia pine, North Carolina pine, sycamore, hard maple and white oak. The tests include the effect of the following factors: lead-hole size, lubrication, holding power when screw is parallel to grain. Anyone interested in this particular problem is advised to consult the original article above referred to.

The general conclusions reached are briefly as follows:

"In soft woods, the size of the lead-hole is important and should be about 70% of the core or root diameter of the screw."

"A lubricant, such as soap, may be used when necessary for easy insert without any grave loss of holding power."

Referring to the holding power:

"In choosing between two adequate screws, use the smaller diameter and longer length when practicable."

"For a given length of screw axially loaded, the holding power increases with the diameter to a certain limit beyond which the increase in diameter decreases the holding power."

A good idea of the relativity between sizes of screws and holding power is given in the following figure (Fig. 2) reproduced from the bulletin above quoted.

‡Principles of Box and Crate Construction, by C. A. Haskett, U. S. Dept. of Agriculture, Technical Bull. 171:46, 1930, Fig. 15.

§Holding Power of Wood Screws, by I. J. Fairchild, Department of Commerce, Bureau of Standards Technologic paper No. 319, 1926.

V. GLUING CHARACTERISTICS OF WOOD

With the increasing refinements in the utilization of wood, the use of glue is coming to be an increasingly important factor. As stated by T. R. Truax of the Forest Products Laboratory*

"The use of glue in the fabrication of wood products brings about more complete utilization of timber through the use of lower grades, inferior species, and small sizes of material; it conserves supplies of clear material and of the scarcer and more valuable woods; and it makes possible a saving of material in the production of articles of unusual form, dimensions, and properties. Nearly every article of glued-wood construction represents an economy in the use of timber resources."

Very little has hitherto been known about the value of different types of glues particularly in relation to different types of wood. The bulletin* just quoted from is a publication which should be consulted by anyone interested in the proper uses of glue and particularly in the proper selection of woods to be used where glue is involved. The Forest Products Laboratory conducted an extensive series of tests with 40 species of wood using vegetable casein and animal glues. "The gluing was done under conditions which cover the general range found in commercial practice."

"The test results are expressed both in percentage of the joint area in which failure occurred in the wood and in the breaking strength in pounds per square inch of joint area. Failure in joints usually occurred partly in the wood and partly in the glue pine. 'Percentage of wood failure' refers to the proportion of the joint area of the specimens where wood fibers were torn away in testing. In Figures 3, 4 and 5 (original Figures 12, 13 and 14), the species are arranged in order of wood failure developed in the tests. Wood failure combined with the shear strength of the joint is used as the criterion for judging the effectiveness of the gluing. Where the wood failure is at or near 100 per cent the joints obviously had been glued satisfactorily, irrespective of the joint strengths obtained. In many species the percentages of wood failure is considerably less than 100 per cent and in such cases the joint strengths must also be considered in determining the success obtained. The strength of the joint in most species is equal to or greater than the calculated strength of the wood itself. The relative positions of the different species with respect to wood failure developed in these tests vary with the different glues, but in general they are similar. Woods of low joint strength, such as Sitka spruce, western hemlock and redwood, show a high percentage of wood failure and woods of high joint strength such as sugar maple, persimmon and white ash, show a low percentage of wood failure. For any one glue the woods giving similar joint strengths vary considerably in the amount of wood failure, and those with lower percentages of wood failure, therefore, require more care in gluing to obtain the full strength of the wood."

The following three figures are the ones referred to: Figures 3, 4 and 5. In the quotation just given, Truax, as a result of his studies, recommends certain gluing schedules for different woods which are reproduced in Tables 4 and 5 herewith.

He calls attention to the fact that necessary prerequisites in all the schedules recommended are properly dried and machined wood, glue spreaders which spread the glue evenly and presses that apply pressure uniformly over the joint.

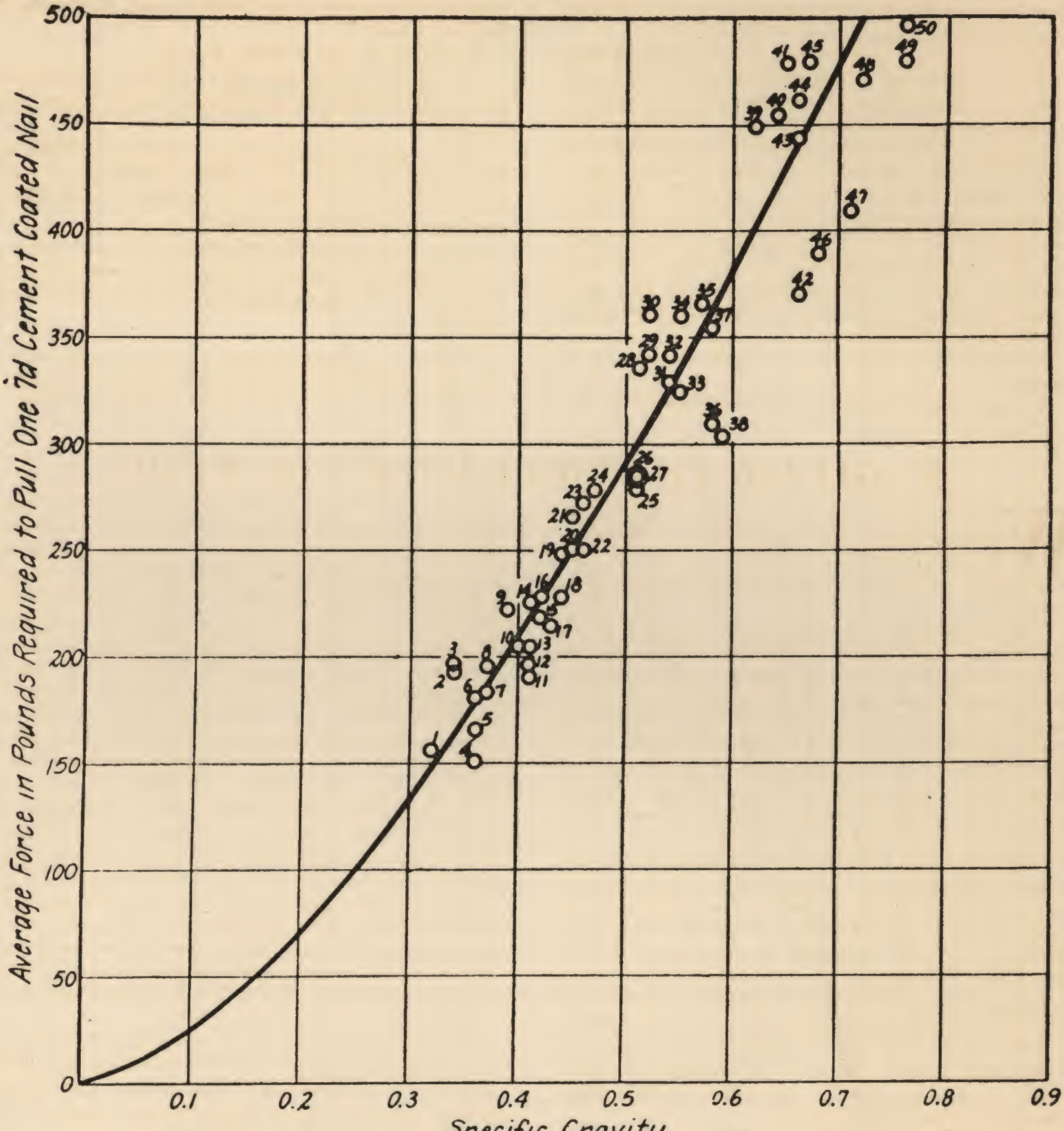
The bulletin from which these extensive quotations have been made contains formulae for the proper mixing of glues; directions for correcting

*The Gluing of Wood, by T. R. Truax, U. S. Dept. of Agriculture, Dept. Bulletin No. 1500, June, 1929. (This publication can be purchased from Supt. of Documents, Government Printing Office, for 25 cents.)

FIGURE 1

From "Principles of Box and Crate Construction," by C. A. Haskett, U. S. Dept. of Agriculture Bulletin 171, page 46.

Relation of specific gravity (based on weight and volume of oven-dry wood) of wood to nail-holding power. 7d cement coated nails driven to $1\frac{1}{4}$ inches depth into the side grain of thoroughly seasoned wood and pulled at once.



KEY TO SPECIES

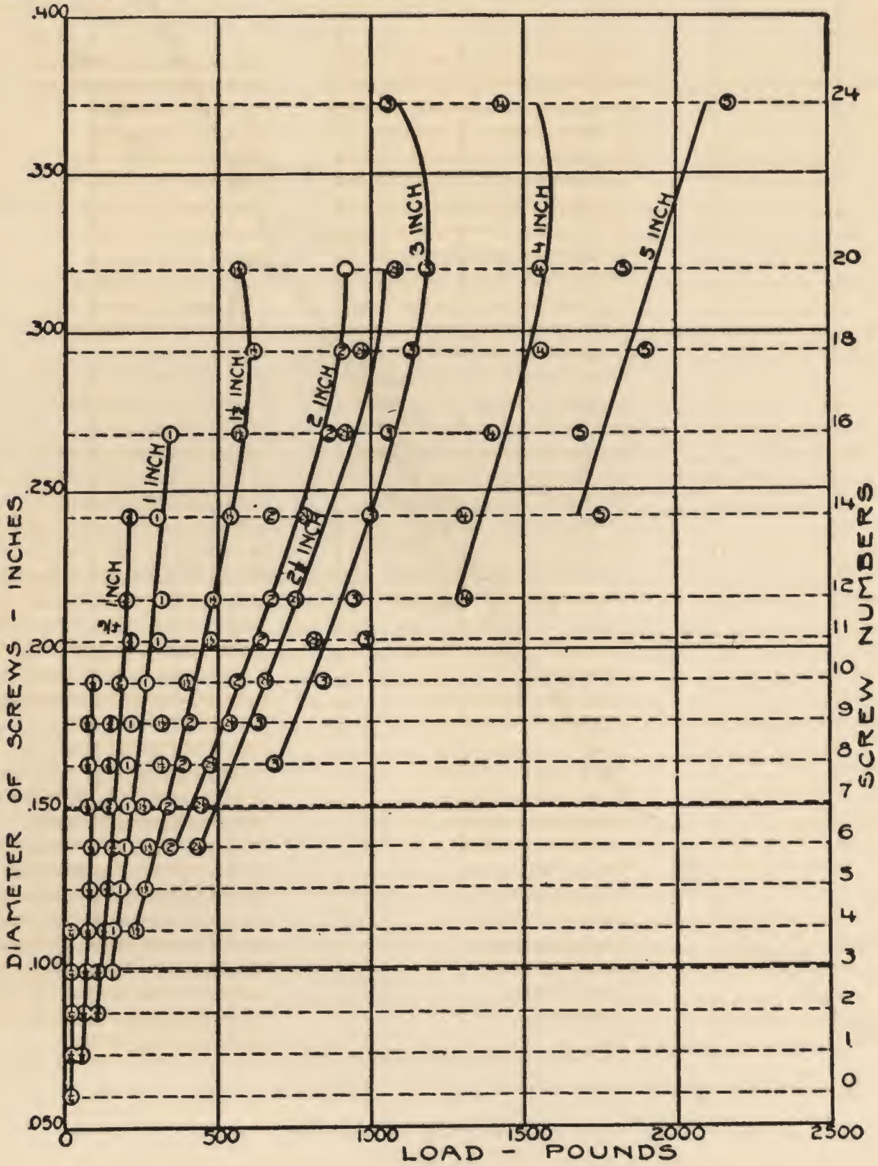
1. Cedar, northern white
2. Cottonwood, eastern
3. Cedar, western red
4. Aspen
5. Fir, lowland white
6. Spruce, Engelmann
7. Fir, California red
8. Cottonwood, black
9. Pine, northern white
10. Fir, silver
11. Fir, white
12. Basswood
13. Aspen, largetooth
14. Spruce, red
15. Poplar, yellow
16. Hemlock, eastern
17. Spruce, white
18. Pine, western yellow
19. Pine, lodgepole
20. Pine, western white
21. Chestnut
22. Pine, jack
23. Hemlock, western
24. Cypress, southern
25. Pine, Norway
26. Douglas fir
27. Gum, red
28. Maple, silver
29. Magnolia, cucumber
30. Gum, tupelo
31. Pine, pitch
32. Elm, American
33. Pine, mountain
34. Sycamore
35. Pine, pond
36. Larch, western
37. Pine, shortleaf
38. Pine, loblolly
39. Maple, black
40. Ash, white
41. Maple, sugar
42. Pine, longleaf
43. Oak, red
44. Birch, yellow
45. Beech
46. Pine, slash
47. Locust, black
48. Oak, white
49. Locust, honey
50. Hop-hornbeam

NOTE: The nail-holding properties of wood are in general closely related to the specific gravity or density of the material, but species characteristics may, however, account for variations of as much as 25 percent in these relations. Since in any species there is variation in specific gravity (one-half of the material falling within about 8 percent of the average specific gravity) the nail-holding properties of individual pieces may vary considerably from the averages presented (one-half of the material falling within about 12 percent of the average nail-holding value for the species). Hence it is possible to select material of any species that is relatively high in nail-holding properties and is better than the average.

FIGURE 2

SCREW-HOLDING VALUES

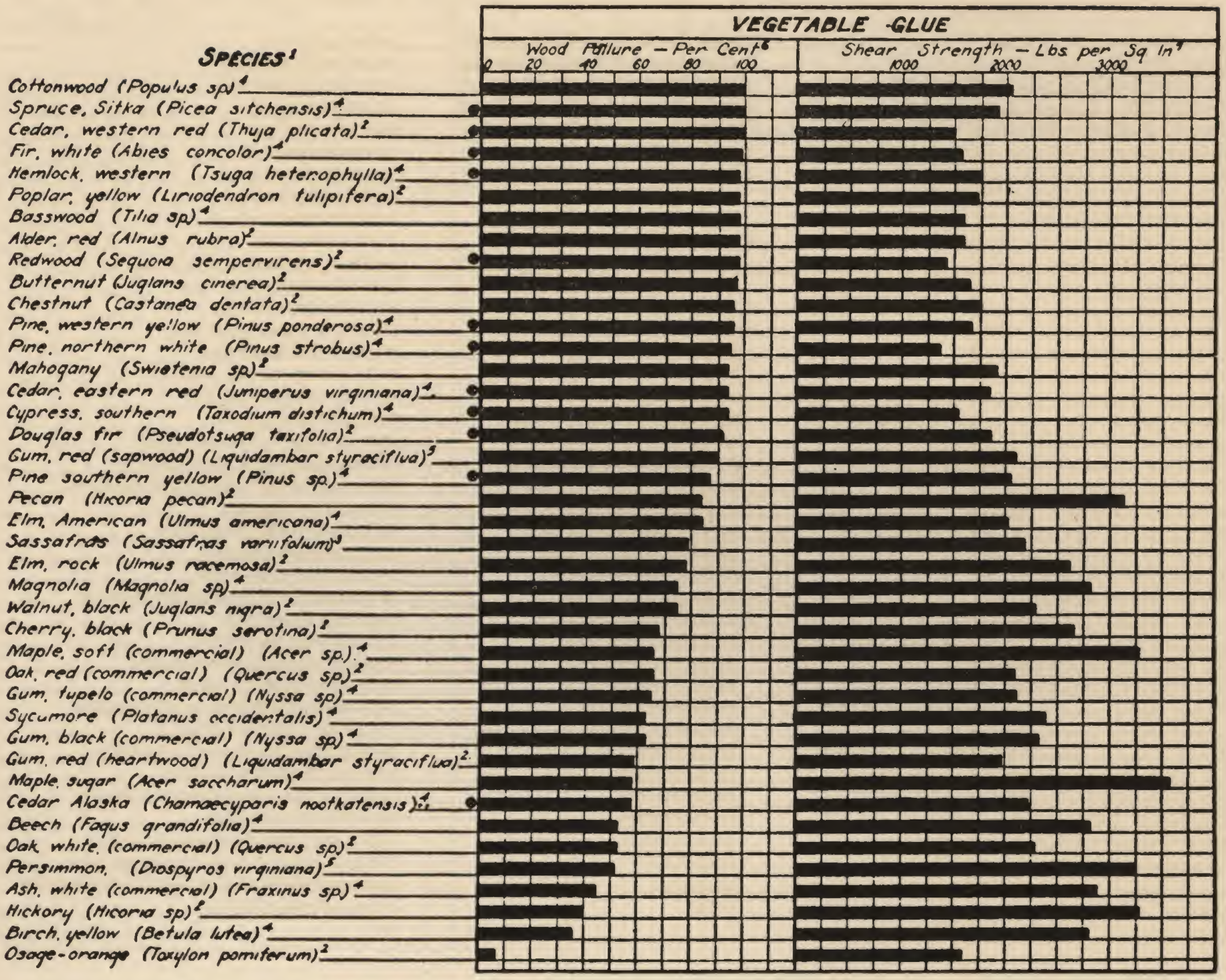
The ordinates are screw diameters with an additional scale to show screw numbers, while the loads are taken as abscissas. Points indicating screws of the same length are connected to form curves.



Cypress, side grain

FIGURE 3

Results of tests on joints of various woods glued with vegetable glue. Values shown are averages of 45 to 180 specimens.

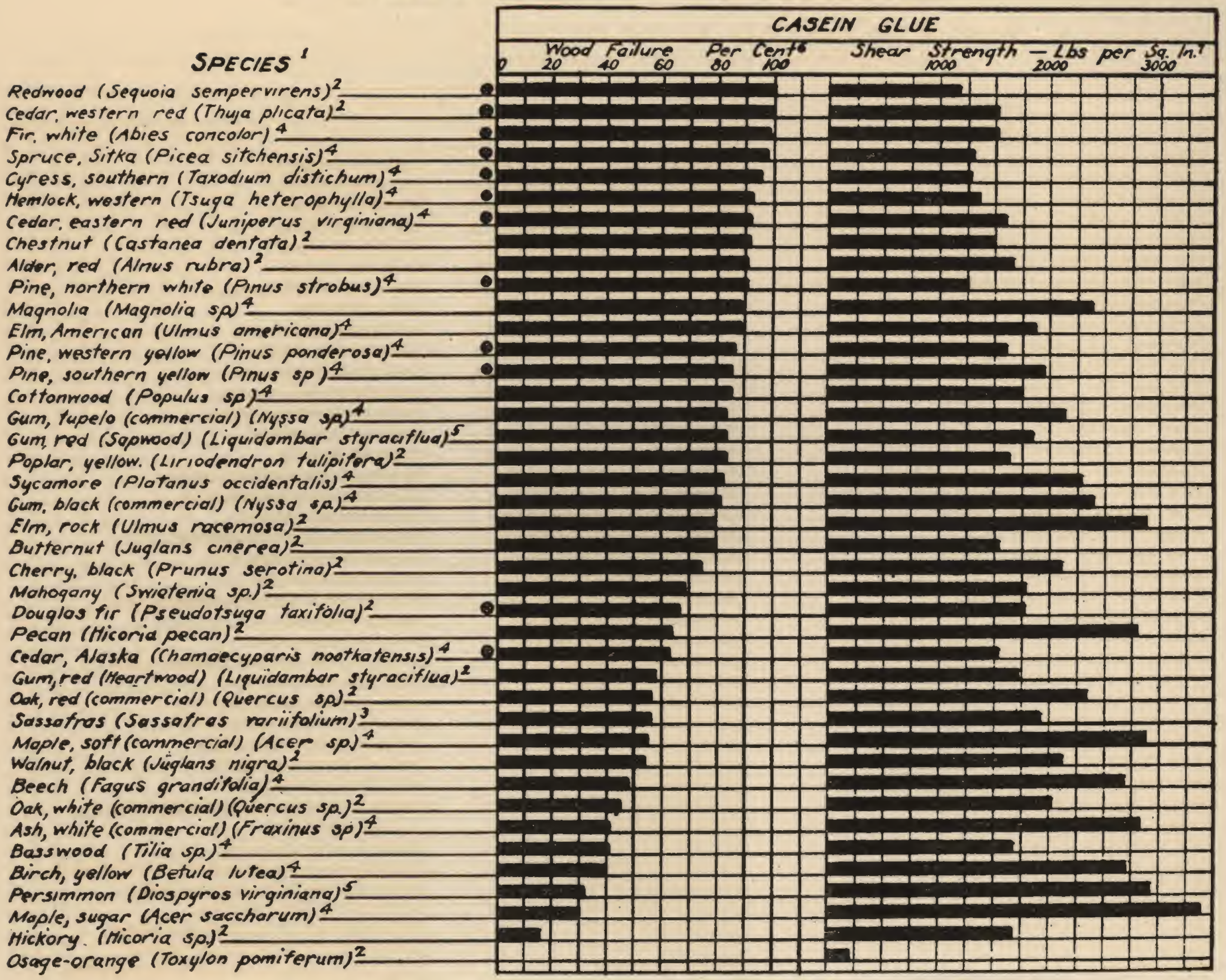


1. Common and scientific names are the standard names given in U. S. Dept. Agri. Misc. Circ. 92 except those designated "(commercial)".
2. Heartwood.
3. Mostly heartwood.
4. Heartwood and sapwood mixed or not identified.
5. Sapwood.
6. Wood failure percent indicates the estimated proportion of the joint area of the specimen where wood fibers were torn away in testing.
7. The shear strength of joints is not comparable with the shear strength of solid wood, published in U. S. Dept. Bul. 556 and elsewhere, due to differences in the test methods and specimens used.

● Indicates woods of the softwood or nonporous class; others belong to the hardwood or porous class.

FIGURE 4

Results of tests on joints of various woods glued with casein glue.
Values shown are averages of 60 to 240 specimens.



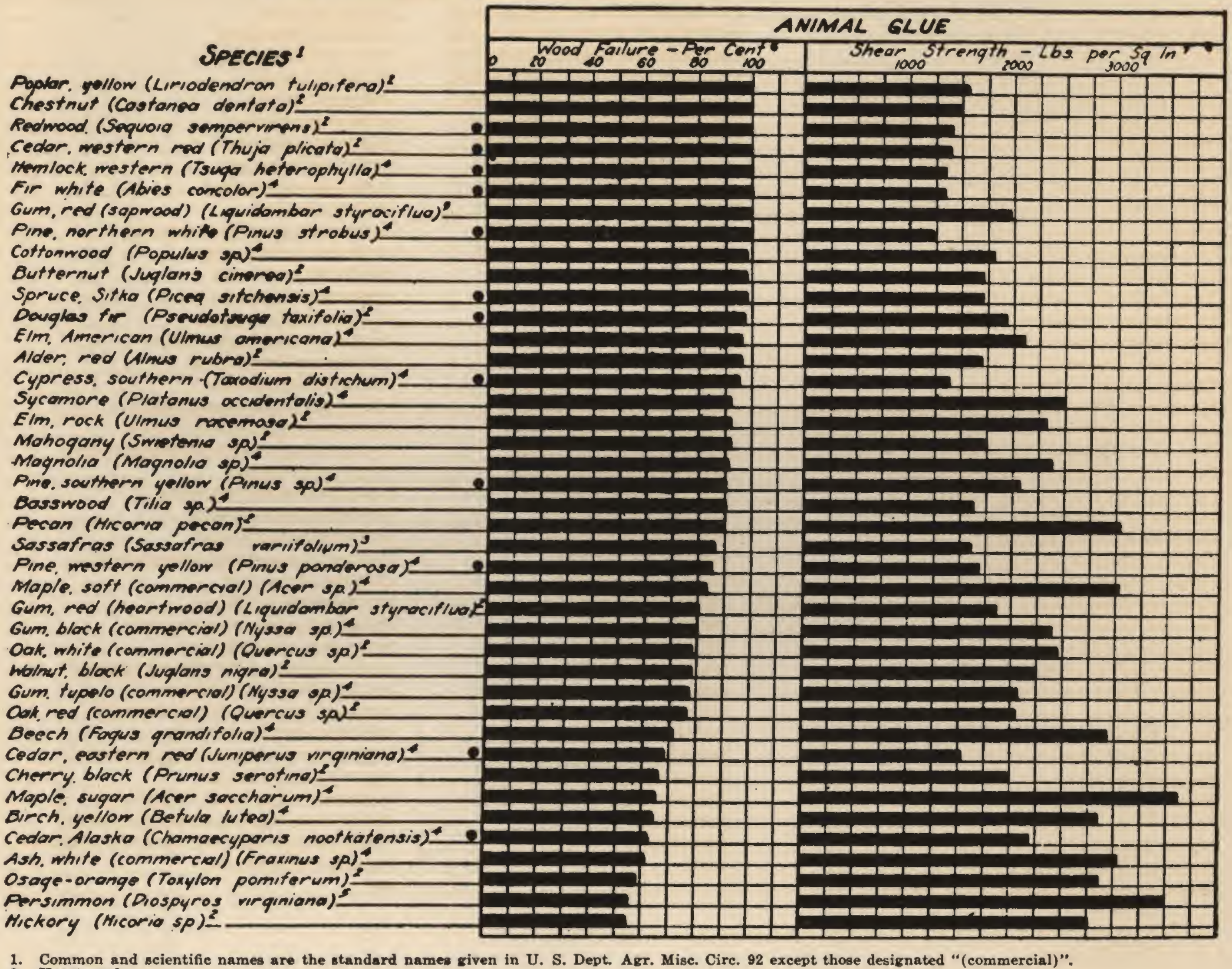
1. Common and scientific names are the standard names given in U. S. Dept. Agr. Misc. Circ. 92 except those designated "(commercial)".
2. Heartwood.
3. Mostly heartwood.
4. Heartwood and sapwood mixed or not identified.
5. Sapwood.
6. Wood failure percent indicates the estimated proportion of the joint area of the specimen where wood fibers were torn away in testing.
7. The shear strength of joints is not comparable with the shear strength of solid wood, published in U. S. Dept. Agr. Bull. 556 and elsewhere, due to differences in the test methods and specimens used.

● Indicates woods of the softwood or nonporous class; others belong to the hardwood or porous class.

FIGURE 5

From "The Gluing of Wood", by T. R. Truax, U. S. Dept. of Agriculture Bulletin 1500.

Results of tests on joints of various woods glued with animal glue under good gluing conditions. Values shown are averages of 30 to 180 specimens.



1. Common and scientific names are the standard names given in U. S. Dept. Agr. Misc. Circ. 92 except those designated "(commercial)".
2. Heartwood.
3. Mostly heartwood.
4. Heartwood and sapwood mixed or not identified.
5. Sapwood.
6. Wood failure percent indicates the estimated proportion of the joint area of the specimen where wood fibers were torn away in testing.
7. The shear strength of joints is not comparable with the shear strength of solid wood, published in U. S. Dept. Agr. Bul. 556 and elsewhere, due to differences in the test methods and specimens used.

● Indicates woods of the softwood or nonporous class; others belong to the hardwood or porous class.

glue defects; detailed directions for the preparation of glues; proper application thereof; and a full discussion of plywood.

For a complete understanding of what may be expected when cypress wood is glued, the bulletin should be consulted. It can be stated, however, that while glued cypress cannot compare in strength of joint with the hardwoods, the tests made by Truax indicate that cypress can be successfully glued, and that when properly done, joints of cypress rank with and in many cases above similar joints of other coniferous woods.

TABLE 4.—GLUING SCHEDULES

Class or gluing schedule	Glue water proportion[1] by weight	Glue spread	Temperature of the wood	Pressure	Closed[2] assembly time
		Lbs. per 1,000 sq. ft. [3]	*°F.*	*Lbs. per sq. in.*	*Minutes*
A1[4]	1 to 2¼	60 to 65	70	100 to 150	0 to 1
	1 to 2¼	65 to 70	80	100 to 150	1 to 5
	1 to 2¼	70 to 75	90	100 to 150	3 to 20
	1 to 3	70 to 75	90	100 to 150	5 to 20
A2[4]	1 to 2¼	65 to 70	70	125 to 175	⅓ to 1
	1 to 2¼	70 to 75	80	125 to 175	2 to 5
	1 to 2¼	75 to 80	90	125 to 175	7 to 18
	1 to 2¾	75 to 80	90	125 to 175	10 to 20
A3[4]	1 to 2¼	65 to 70	70	150 to 200	½ to 1
	1 to 2¼	70 to 75	80	150 to 200	3 to 5
	1 to 2¼	75 to 80	90	150 to 200	10 to 18
	1 to 2½	75 to 80	90	150 to 200	12 to 18
C1[5]	1 to 2	60 to 70	70 to 90	100 to 150	0 to 15
	1 to 2⅕	70 to 80	70 to 90	100 to 150	3 to 20
C2[5]	1 to 1⅘	70 to 75	70 to 90	150 to 200	0 to 12
	1 to 2	75 to 80	70 to 90	150 to 200	5 to 20
V1[5]	1 to 2⅛	60 to 70	70 to 90	100 to 150	0 to 20
	1 to 2¼	70 to 80	70 to 90	100 to 150	1 to 25
V2[5]	1 to 2⅛	70 to 75	70 to 90	150 to 200	5 to 20
	1 to 2¼	75 to 80	70 to 90	150 to 200	5 to 25

[1]The recommended proportions of glue and water are in general suitable for both lumber and veneer gluing but ordinarily it is better to use thicker glue mixtures with lumber than with veneer.

[2]Wood pieces laid together as soon as spread with glue.

[3]Weight of wet glue mixture.

[4]An animal glue equivalent to about a No. 12 in the National Association of Glue Manufacturers grades. Other grades may be used by making suitable adjustments in the glue-water proportion.

[5]Average prepared casein and vegetable glues; some commercial glues require more or less water to obtain the same consistency of mixture.

TABLE 5.—INDEX OF GLUING SCHEDULES FOR DIFFERENT WOODS
[H=heartwood; S=sapwood; M=heartwood and sapwood mixed]

Species	Animal glue	Casein glue	Vegetable glue	Species	Animal glue	Casein glue	Vegetable glue
	Schedule	*Schedule*	*Schedule*		*Schedule*	*Schedule*	*Schedule*
Alder, red....M	A2	C1	V1	Gum, red....H	[1] A3	[1] C2	[1] V2
Ash....H	A3	C2	V2	Do....S	A3	C2	V2
Do....S	A3	C2	V2	Gum, tupelo....H	[1] A3	C2	V2
Basswood....M	A3	C2	V1	Gum, tupelo....S	A3	C2	V2
Beech....H	[1] A3	[1] C2	[1] V2	Hemlock, western....M	A1	C1	V1
Do....S	A3	C2	V2	Hickory....M	A3	[1] C2	V2
Birch....H	[1] A3	[1] C2	[1] V2	Magnolia....H	A3	C2	V2
Do....S	A3	C2	V2	Do....S	A3	C2	V2
Butternut....M	A2	C2	V1	Mahogany....H	A2	C2	V2
Cedar, Alaska....M	A2	C2	V2	Maple, soft (commercial)....M	A3	C2	V2
Cedar, eastern red....H	[1] A3	C1	V1	Maple, sugar....M	A3	C2	V2
Do....S	A2	C1	V1	Oak, red....M	A3	C2	V2
Cedar, western red....H	A1	C1	V1	Oak, white....M	A3	C2	V2
Cherry, black....H	A3	C2	V2	Osage orange....H	[1] A3	[1] C2	[1] V2
Chestnut....M	A1	C1	V1	Pecan....H	A2	C2	V2
Cottonwood....M	A2	C2	V1	Persimmon....S	A3	C2	V2
Cypress, southern....H	A3	C1	V1	Pine, northern white....M	A1	C1	V1
Do....S	A1	C1	V1	Pine, southern yellow....M	A2	C2	V2
Douglas fir....H	A1	C2	V1	Pine, western yellow....M	A2	C1	V1
Elm, American....M	A3	C2	V2	Poplar, yellow....M	A2	C2	V1
Elm, rock....M	A3	C2	V2	Redwood....H	A1	C1	V1
Fir, white....M	A1	C1	V1	Sassafrass....M	A2	C2	V2
Gum, black....H	[1] A3	C2	[1] V2	Spruce....M	A1	C1	V1
Do....S	A3	C2	V2	Sycamore....M	A3	C2	V2
				Walnut, black....M	A3	C2	V2

[1]Treatment of the wood before gluing as described on page 48 of U. S. Dept. of Agriculture Bulletin No. 1500 is recommended where the strongest possible joints are required.

VI. TASTE AND ODOR

It is frequently necessary that material used in the manufacture of packages for shipping foods or for the construction of barrels or tanks containing liquids, should give the minimum discoloration and odor to the materials contained in same. An extensive investigation has shown that very little taste, color, or odor is transmitted by cypress containers. Reference is herewith made to the discussion on this subject in the paper by Hauser and Bahlman, reprinted in Chapter VII, page 17. These investigators soaked various species of wood in cold water and in hot water. They found that cypress, fir and pine yielded no colors when subject to cold water and that when subject to boiling water, cypress lost most of its color after the third boil and all of it after four hours of boiling. Fir and pine when subject to cold water yielded no color and when subject to the eighth boil still showed slight traces.

These investigators also made some tests as to the taste imparted to the water and found that cypress was the only wood that imparted neither color nor taste after being in the water for a few days.

They also made extensive tests relative to color extractions by means of cold acids and alkalies and cold salt solutions. The results will be found on page 20.

In 1908, the writer made some tests to determine to what extent color and odor were imparted by the various woods to artificial wine made up as follows: Water, 90 litres; 95-per-cent alcohol, 10 litres; tartaric acid, 400 grams; glacial acetic acid, 100 cc. The woods included in this test were red cypress, redwood, incense cedar, western red cedar, Sitka spruce, western red cedar from Idaho. These woods were soaked 4 weeks in this artificial wine and at the end of this period the liquid was carefully examined and it was found that practically all, with the exception of the red cypress, had not only a very decided color, but in most instances a very disagreeable taste. The liquid in which the red cypress had been immersed, using light and very dark pieces of cypress, showed practically no color and had no foreign taste. The results of these tests were submitted in a competition to find a substitute for white oak for storage of wine. The California Wine Association, after an investigation of these tests, prepared a number of barrels of cypress and stored wine in same without any deleterious results.

When wood is subject to solvent action of various substances such as hot or cold water, ether, weak solutions of sodium hydroxide, etc., certain substances can be removed from the wood.

*"The extraneous components of wood are often of such great commercial interest that the determination of extractives become an important matter. A wood high in ether-soluble matter usually contains large amounts of resin (*e. g.*, the lightwood of Southern pine). A large percentage of water-soluble material might give a clue or indication of a high percentage of tannins, coloring matter (or its precursors), or even of valuable water-soluble carbohydrates (*e. g.*, the galactans of Western larch). The determination of water-soluble or alkali-soluble extractives may also be of decided value in determining whether or not a wood should be used in the manufacture of various types of storage tanks."

The following table (6) is quoted from Hawley and Wise, page 175 (with certain additions since made by the U. S. Forest Products Laboratory):

*Hawley and Wise, The Chemistry of Wood, 1926, p. 174.

TABLE 6—CONTENT OF EXTRACTIVES IN WOODS

(From Hawley and Wise, "The Chemistry of Wood")

Species	Soluble in			
	Cold Water	Hot Water	Ether	1 Per cent NaOH
	Per cent	*Per cent*	*Per cent*	*Per cent*
Basswood	2.12	4.07	1.96	23.76
Cedar, Alaska, first sample	2.47	3.11	2.55	13.41
Cedar, Alaska, second sample:				
Sapwood	2.13	3.41	1.00	11.72
Heartwood	2.88	4.12	1.32	12.77
Cypress, first sample:				
Sapwood	0.72	1.42	0.23	8.55
Heartwood	2.79	2.99	4.87	10.59
Cypress, second sample:				
Sapwood	1.76	2.30	2.80	10.63
Heartwood	3.27	3.49	7.93	13.56
Douglas Fir, first sample	3.54	6.50	1.02	16.11
Douglas Fir, second sample:				
Springwood	3.00	4.67	....	15.10
Summerwood	2.15	3.76	....	14.56
Larch, Western	10.61	12.59	0.81	22.14
Pine, Northern White:				
Sapwood	3.55	5.15	5.46	17.16
Heartwood	5.97	7.68	3.62	19.15
Pine, Western White	3.16	4.49	4.26	14.78
Pine, Western White:				
Springwood	3.76	5.16	....	22.08
Summerwood	4.29	5.42	....	21.47
Pine, Western Yellow	4.09	5.05	8.52	20.30
Pine, Longleaf	6.20	7.15	6.32	22.36
Pine, Loblolly:				
Sapwood Springwood	3.28	3.49	....	11.11
Sapwood Summerwood	2.18	2.97	....	11.01
Heartwood Springwood	7.50	7.16	....	18.14
Heartwood Summerwood	7.64	6.44	....	21.19
Poplar:				
Sapwood	1.29	1.98	0.27	16.74
Heartwood	1.50	2.08	0.43	17.70
Redwood	7.36	9.86	1.07	20.00
Spruce, White	1.12	2.14	1.36	11.57

The figures in this table simply indicate that there are certain substances which can be extracted that need not necessarily indicate either harmful or useful substances. The study of these figures, however, may warrant the statement that woods with the lowest percentage of extractives for any given material may be assumed to show the greatest inertness when subject to liquids with solvent properties. The figures in this table for cypress for instance check determinations made as to the slight influence which cypress wood has on materials with which it comes in contact. The exact meaning of higher or lower extractives will not be understood until much more is known concerning these extractives. The table and quotation above given should be taken not by themselves but together with other experiences herein enumerated (see Chapter VII, page 16).

Another test reference taste, is one that was made in 1920 under the auspices of the Dairy Division of the U. S. Dept. of Agriculture at Grove City, Pa. Four boxes, each of the following kinds of wood were used, tulip poplar, white ash, Eastern hemlock, Southern pine, cypress, red gum, Sitka spruce, cottonwood, Eastern spruce, Northern white pine and Pondosa pine. These boxes were packed with two pounds of butter made from unripened pasturized sweet cream. One box of each was paraffined; all were lined with parchment paper. The boxes were then placed in a refrigerator, and a temperature varying from 34° to 40° F. was maintained for 10 days. The boxes were then removed and the surface was examined for woody flavours by a committee of three members of the Dairy Division of the U. S. Dept. of Agri. and one representative of the United States Forest Service. "Our tentative conclusions," they reported, "are that hemlock, cypress and Sitka spruce may be used for butter containers without imparting to the butter sufficient woody flavor to be commercially objectionable."

The results of the tests mentioned indicate that cypress is a wood which gives very little color, odor or taste to materials contained therein. Such a quality will of course have to be taken into consideration in connection with other factors, such as strength, lasting power, water absorption, etc.

VII. RESISTANCE TO CHEMICALS

Cypress has always been one of the principal woods used for the construction of tanks and vats. Experience in chemical industries indicates that cypress wood had certain qualities which made it particularly resistant to the action of commonly used acids and alkalies. This fitness or chemical inertness applied not only to specific chemical industries but to such industries as used vats in the preparation of foods, wines, etc. The use of wood in the chemical industries was made the subject of an interesting discussion by Clark S. Robinson, who has stated the case so well that the introduction of this article is herewith quoted in full:*

"The value of wood as a construction material in the chemical industries is very commonly underestimated. This arises from the fact that little information is available in the literature in regard to the use of wood for such purposes, and it is often true that on account of lack of information the plant operator makes use of unsuitable wood, or puts it to improper uses. It is the purpose of this article to give a fairly comprehensive outline of the various woods and their uses for chemical plant work.

Chemical apparatus made of wood is usually less expensive in its first cost than when made of metal. In many cases the difference in favor of wood is great. When used for water or other liquids which do not destroy the wood, the life of the wood is very long. Cypress tanks are known to have lasted for 130 years, while wooden water pipes have been in service underground for 100 years, such life being much in excess of that obtained from the ordinary steel of today. In many localities, the water contains material which quickly corrodes the best of steels while wood is quite unaffected. Wood does not require frequent painting to prevent corrosion as is the case with steel, and it can usually be repaired or remodeled by the local carpenter.

Wood is a poor conductor of heat, and wooden apparatus exposed to frost requires much less heat to keep the contents from freezing than is the case with metals. Conversely, the contents of tanks and piping can be kept cold more easily when wood is used.

Wooden piping is not common in chemical plants, but it has many advantages, among which are the absence of corrosion due to electrolysis by stray electric currents, and its greater carrying capacity under given pressure drop. Its value may be indicated by the fact that one large chemical plant in this country has nearly one hundred miles of wooden pipe. Its cost is also less than that of iron or steel, considerably so in the larger sizes.

Wood is not a suitable material for use in apparatus handling strong oxidizing agents, such as concentrated nitric or sulfuric acids. It is readily attacked by strongly alkaline solutions. It must be protected by a suitable protective coating from the action of certain chemicals, such as concentrated hydrochloric acid.

Wood is mechanically weaker than metals, and this limits the use of apparatus of comparatively moderate pressure, steel-banded wooden pipe having been used up to 130 pounds pressure, and reinforced tanks up to 50 pounds pressure.

Wooden tanks and piping swell when brought into contact with liquids, and shrink if allowed to dry out afterwards. This permits the joints of the apparatus to open up and leaks develop. The apparatus must therefore be kept full of liquid and,

*Wood as a Chemical Engineering Material, by Clark S. Robinson, from the Dept. of Chemical Engineering Mass. Inst. of Technology, Journal of Ind. and Eng. Chem. Vol. 14, July, 1922, p. 607.

if this is not practicable, it should be filled with water to prevent drying out.

The kinds of wood most commonly met with in this country are listed below in the approximate order of their popularity for chemical work in general.

1. Red Gulf or Louisiana Cypress (Taxodium distichum).
2. Long Leaf Yellow or hard pine (Pinus palustris).
3. California Redwood (Sequoia sempervirens).
4. White Pine (Pinus strobus).
5. Douglas, Washington, or Oregon Fir (Pseudotsuga taxifolia).
6. Hard Maple (Acer saccharum).
7. Yellow Poplar (Populus deltoides).*
8. White Oak (Quercus alba).
9. Tamarack (Larix laricina).
10. Spruce (Picea rubra).
11. Norway Pine (Pinus resinosa)."

It is difficult to explain the reason why a wood like cypress should be so resistant to the actions of chemicals. The following quoted from Hawley and Wise (p. 307) †, probably states the matter as clearly as anything which could be given:

"The mechanism of the protection against the attack of chemicals is probably different from that of protection against decay. We have seen that resistance of wood to decay is due largely to the toxic action of certain extraneous materials on the fungus, but it is difficult to conceive that the extraneous material acts as a 'poison' or negative catalyst of, for instance, the hydrolysis of wood by dilute acids in the cold. It seems more likely that the extraneous material, itself resistant to the action of the chemical, furnishes a mechanical protection for the wood. This conception is not difficult to follow in the case of the protection offered by resinous materials against the action of acids, but it does not explain so readily the apparent protection by materials soluble in dilute acids against resistance of woods with known composition of extraneous materials against certain chemicals to make further speculation of this kind profitable."

The most exhaustive investigation on the effective resistance of the various species of wood to various chemicals was made by S. J. Hauser and Clarence Bahlman of the Hauser Stander Tank Company. This investigation was so fundamental, that it is referred to not only by Hawley and Wise, is also included as a large part of his paper by Clark Robinson, but is copiously abstracted and forms the entire subject matter on "Resistance of Woods to Chemicals" in the Chemistry of Cellulose and Wood, by A. W. Schorger, 1926, pages 375-379.

In view of the significence of the Hauser and Bahlman investigation, and by courtesy of the Hauser Stander Tank Company, their paper herewith follows in full: A study of the data presented by these two investigators will enable a prospective user to intelligently select the wood best used for his particular purpose.

*This line is as originally printed in Professor Robinson's article. However the name for Yellow Poplar is wrong and should be Liriodendron tulipifera.

†Same reference Hawley-Wise given before.

A STUDY OF THE ACTION OF VARIOUS CHEMICALS UPON DIFFERENT WOODS USED FOR CHEMICAL TANKS

By S. J. Hauser and Clarence Bahlman

Considerable thought has been focused recently upon the suitability of wood as a material for making tanks and vats to hold liquids of widely different natures and concentrations. While wood tanks have been generally employed for holding chemical solutions in the factory it was not always known which wood was the best suited for any specific liquid. At times, on account of the scarcity or high cost of metal equipment, manufacturers have installed wooden accessories, and soon came to recognize many unsuspected advantages possessed by the latter. Often, however, a manufacturer hesitates to risk the purchase of wooden equipment because both he and the tank builder are unacquainted with the ability of the material to withstand the usage to which the tank must be put.

It appears to us that a well worked out series of chemical experiments would yield information which, while not solving all of the problems, would at least go a long way toward clearing up some of the doubts which constantly beset both the user and the manufacturer of wooden tanks and vats for chemical purposes. Evidently the resistance to chemical action must vary considerably with different woods, and the object of our studies has been to ascertain the relative resistance of different woods, both in the natural state and also when covered with so-called acid-proof paints, to the action of well-known chemicals in various strengths, at room temperature and at 100° C or above.

The limitations of our tests were recognized at the outset. It was known, of course, that the ordinary strains and rough treatment which a wooden tank must suffer in the plant cannot be duplicated in the laboratory, and that the life of a wooden tank or vat in an industrial establishment is governed not only by its resistance to the contained chemical, but also by the skill and care used in its construction, and the intelligence with which it is handled by the plant operatives. Owing to the limited time in which to make these experiments, we have included only those woods in this study, which are most commonly employed in making wooden tanks. Chemical analysis to show the extent to which a liquid is contaminated, or altered in strength and composition when in contact with wood, moreover, would have been a valuable contribution to our knowledge, but the time and labor required for such tests would have been prohibitive.

Although the adaptability of a wood for the purposes in which we are interested cannot be conclusively determined by laboratory experiments alone, it still remains a fact that such experiments are a wonderful help in explaining the failure of a wooden tank, on one hand, and in helping us to avoid future failures on the other. Laboratory results and factory experience should each be studied with an open, "give and take" mind, and

one will be more likely to reach the proper conclusion by a judicious consideration from both viewpoints.

We therefore feel justified in submitting our results, incomplete as they are, because they have assisted us in many of our problems and have furnished us with a clearer conception of just what might be expected of any of our common woods, when exposed to the action of chemicals. This laboratory study has eliminated considerable guesswork, and has made us feel more confident as to the behavior of our tanks and vats.

Woods Used — Six woods were used in these experiments: red gulf cypress, Douglas fir, long leaf yellow pine, California redwood, hard maple, and white oak. Uniform test-strips 4"x1"x¼", were prepared from each of the woods, thoroughly air-seasoned, and only those strips which were free from knots and other imperfections were used in the experiments.

Outline of Experiments — Our tests were confined primarily to a study of the effect of various hot and cold liquids upon wood, rather than to the converse, the effect of the wood upon the fluid. The latter, however, comes within our notice to the extent that a record was kept of all colors assumed by the different solutions and liquids.

The degree to which the woods were acted upon and the fitness of the wood for use with various liquids was judged from a quantitative determination of the amount of fluid absorbed by the wood, the extent to which the wood suffered swelling or shrinkage and also by physical manifestations such as softness, brittleness, warping, disintegration, etc.

The strips were carefully weighed and calipered (in thickness) to .001 of an inch just prior to inserting them into the solutions. Ordinary glass water tumblers were used for the room temperature tests. The strips fit nicely in these tumblers and it was possible to weight them down by laying a piece of heavy glass tubing over the top of tumbler; in this way the wood was kept completely submerged in the liquid. For the tests with hot liquids the strips were cut in half so that they would float upon the surface of 100 cc of the hot liquor in a 200 cc Erlenmeyer flask. A separate container was always used for each strip.

Length of Exposure to the Chemical — In the tests conducted with the cold solutions (room temperature) the data for amount of solution absorbed and for changes in dimensions were obtained after one week's soaking in the liquid. After these determinations the specimens were returned to their proper solution for an additional three weeks' immersion.

In the tests with hot or boiling liquids, the liquid was boiled for one hour upon each of eight days, the fluid and the test strip being at room temperature during the intervals between the boilings.

Strips which were coated with asphalt or coal tar material, as described later, were submerged in cold solutions for a period of three weeks.

Chemicals Used — The liquids used include ordinary acid, alkalis and salts in different concentrations, as mentioned later on, and also linseed oil, turpentine, and distilled cottonseed-oil fatty acids. The latter is a solid which melts slightly above room temperature.

Details of the Experiment — A description of some of the more important details and terms used in this study will be given here.

After one week's immersion in the liquids at room temperature, the strips were removed, dried upon the outside with a rag and allowed to remain for fifteen minutes upon the laboratory desk in order to permit surplus liquid to evaporate from the surface of the wood strip. They were then weighed and the amount of liquid absorbed was calculated. This was expressed as "percentage gain in weight" and also as grams of liquid absorbed per strip, *i. e.* per cubic inch.

After obtaining these weights, the specimen strips were calipered. In the great majority of cases, the strips, at this point, showed increase in dimensions. This increase, expressed as a percentage of the original dimensions, we have termed "Temporary Expansion," since considerable of it is lost when the wood is allowed to dry in the air.

After weighing and calipering the moist woods as described above, the strips were placed upon their sides and allowed to dry in the room for one week, after which they were again calipered. From this measurement is obtained what we have designated as "Permanent Expansion."

The strips were then placed in fresh solutions and allowed to remain therein for three weeks, after which their physical condition was recorded. Brittleness and pliability were detected by attempting to break the strip in the hands; varying degrees of softness was detected by pinching between the fingers and by tapping the woods with the point of a sharp lead pencil held in a vertical position, using a slight amount of force. The other terms used in describing the condition of the wood specimens are self-explanatory. A record was also kept of colors imparted to the liquids, as well as of other observations of interest.

With the hot solutions the strips were weighed and calipered within a few seconds after removing from the hot liquid and drying with a rag, since to allow them to lie for fifteen minutes would have permitted considerable of the absorbed water to evaporate. Gain in weight, temporary and permanent expansion and the condition of the woods were determined and recorded as in the case of the cold tests.

Discussion of Data Obtained — Using the foregoing technique, the action of any chemical upon a wood may be judged from four standpoints:

1. Colors extracted from the wood by the liquid.
2. The extent to which the liquid is absorbed by the wood.
3. The swelling or shrinkage of the wood as a result of contact with the liquid.
4. Other effects upon the wood, such as softness, brittleness, cracking, etc.

To present our results in detail would be a burden to the reader, and it is our intention to discuss them briefly and in a summarized fashion which will emphasize only the more important features.

I—COLORS EXTRACTED FROM WOODS BY VARIOUS LIQUIDS

The extraction of color from wood can be accounted for in two ways: First, the liquid acts merely as a solvent for coloring matters contained in the wood, there being no pronounced chemical change or evidence of destructive action of the chemical upon the wood. Secondly, the color is due to substances formed by the breaking down of the woody material under the action of the chemical.

The color assumed by water contained in wooden vessels is of course to be explained as under the former. On the other hand, the dark brown and black color assumed by strong acids and alkalis is to be attributed to the disintegration of the wood, although some of it is also due to the extraction of pigment. Pronounced colors, therefore, usually accompany a destructive action upon the wood; colors of lesser intensity have little significance as indicators of action upon the wood.

In many chemical processes involving the use of wooden containers, such as acid pickling, the manufacturer is interested only in having the acid perform the function for which it is intended and in preserving his wooden tank as long as possible. Colors taken up by the liquor from the wood are of little moment. In other cases, however, it is undesirable to have the liquid become noticeably tinted. Any wood which persists in imparting color to water used for drinking or laundry purposes, to the raw materials from which a colorless soap is to be prepared, or to various food and other products, cannot be expected to be favorably received by these trades. Color, therefore, assumes importance in some fields, in others it is of little import.

A—Colors Extracted by Water

Cold Water — To determine the relative degrees to which color is imparted to cold water by the various woods, the strips were placed in tumblers full of distilled water. Fresh water was added every twenty-four hours up to the fifth day. For four days thereafter the water was replenished only every forty-eight hours and after the eighth day the strip was left in the water for one week. A subsequent two weeks soaking in fresh water completed the test.

In this way it was possible to compare the relative intensity of the colors from the different woods, as well as the time required to exhaust the pigment from the sample strips.

Oak and redwood yielded very pronounced color to the water within 24 hours or less. Thereafter no color could be extracted from these woods by further 24-hour immersions, but 48 hours exposure again showed color. A second 48 hours extraction still yielded color from the oak but not from the redwood. Both woods, however, showed decided tints when subsequently soaked for one week. The final 2 weeks immersion still showed a pronounced color from the oak, but only a faint tint was yielded by the redwood.

Maple imparted no color to the water when soaked for four 24 hour periods. The first 48 hours immersion showed only a faint coloration; the second 48 hours test showed no color. The one week immersion again showed a slight tint, but at this time most, if not all, of the coloring matter had been extracted, since the two weeks test was devoid of color.

Cypress, fir and pine failed to yield colors by any of these tests.

Boiling Water — The strips were boiled in large beakers of distilled water for one hour upon each of 8 days. Fresh water was used for each boiling. The relative persistence with which the samples imparted color to the water is shown in the following table.

Table No. I — No. of Boilings Showing:

	Strong Color	Slight Color	No Color
Cypress	3	1	4
Pine	2	6	0
Fir	5	3	0
Maple	5	3	0
Oak	8	0	0
Redwood	8	0	0

Summary — Oak and redwood contain a large amount of coloring matter which is freely given up to water. In cold water the redwood pigments are exhausted somewhat earlier than those of the oak; in boiling water both woods yield pronounced colors even after 8 hours of boiling. These woods, therefore, are more apt to yield objectionable colors to water and aqueous solutions than are the other woods.

Maple yields only slight color to cold water, but this becomes exhausted after a short time. With hot water a decided color (less intense, however, than that from oak and redwood) is still extracted after 5 hours of boiling, but further boiling yields only traces of color.

Cypress, fir and pine yielded no colors whatsoever to cold water, under the conditions of this test. With boiling water the cypress had lost most of its coloring powers after the third boiling, and all of it after 4 hours boiling. Cypress is the only wood from which the coloring substances were exhausted so soon. Fir and pine, while exhibiting no color in cold water, still showed slight traces at the end of the 8 boiling tests, but the intensity of the colors from the pine were decreasing much more rapidly than that from the fir.

Conclusions — Obviously a larger volume of water might show a coloration which would escape detection in our small-scale experiments. Also, the relative proportion of water and wood in contact with one another is another factor governing intensity of color. Keeping in mind the merely relative nature of our tests, we may draw the following conclusions in regard to the color imparted to hot and cold water by the six woods.

Undoubtedly all dissolved pigments would eventually be extracted even from oak and redwood, but it would require many changes of water to accomplish this. Where it is desired to avoid this rather lengthy process of breaking in, and in order to obtain a colorless water from a new tank, redwood and oak are less adapted than the other woods. Cypress and pine are most suited for either hot or

cold water, with fir and maple standing next in order of usefulness. The colors contained in the latter woods would be extracted after a comparatively short time.

Tastes Imparted to Water — The water used in the foregoing color experiments was tasted from time to time and the results will be given here.

With cold water, all of the six woods gave a distine "woody" taste after the firse and second 24-hour extractions. The taste from the pine was especially pronounced. No tastes were obtained thereafter from cypress, maple and redwood, even after the one-week and two-week soaking. Oak failed to give any taste after the third 24-hour immersion. Fir and pine, however, continued to give tastes until the close of the experiment, although that from the fir was very faint after the final two-weeks' immersion. The pine, however, persisted in yielding an intense woody taste.

With boiling water the tastes naturally were intensified. After the 8 hours of boiling, the fir and pine still yielded a very strong taste, while that from the other woods, although not so pronounced, was still noticeable.

Fir and pine, therefore, are to be considered as woods which will impart disagreeable tastes for quite some time, and these woods should not be used as containers for edible products, unless the taste-producing constituents are thoroughly extracted beforehand.

Oak and redwood, therefore, will not yield tastes after a few days, but persist in imparting colors to the water. Fir and pine are the converse of oak and redwood; that is, they persist in imparting taste but yield no color. From the standpoint of color and taste, then, we may summarize our findings as follows:

1. Oak and redwood are objectionable from the standpoint of color.
2. Fir and pine are objectionable from the standpoint of taste.
3. Cypress is the only wood which imparts neither color nor taste, after a few days. Maple is the nearest to Cypress in this respect.

B—Colors Extracted by Cold Acids and Alkalis

Color cannot be avoided when the woods are exposed to the stronger chemicals, but they may be minimized or evaded entirely with weaker solutions by choice of the proper wood. Just as in the case of water, oak and redwood yield considerably more color to other liquids, than do the other woods.

Colors in the various solutions, as reported below, were obtained after 7 days' immersion in the solution.

Acetic Acid — 5% and 25% acetic acid remains uncolored by cypress, fir, maple and pine, but becomes light brown when in contact with oak and redwood. Fifty per cent and glacial acetic acid withdraw only light yellow tints from the first mentioned woods, but darker brown colors from oak and redwood.

Hydrochloric Acid — In 5% and 10% concentration this acid assumes a light brown color when exposed to oak and redwood, but even 25% hydrochloric acid is not tinted by the other four woods. Colors ranging from light yellow to opaque black are withdrawn by the 50% acid from all the woods except cypress; the latter yielding no color. All the woods are considerably attacked by concentrated hydrochloric acid, the solution in all cases becoming opaque black.

Sulphuric Acid — Ten per cent and weaker dilutions of sulphuric acid remain uncolored by cypress, fir, maple and pine, but oak and redwood yield colors even to a 1% solution of this acid. All of the woods, except fir, yield colors to 25% sulphuric acid.

Nitric Acid — Five per cent nitric acid is colored deep yellow by all of the woods. This color seems to be due more to the formation of oxides of nitrogen from the acid than to any pigments from the wood, since the colors are practically identical with all of the samples.

Caustic Soda — Even in 1% concentration this alkali extracts colors from all of the woods, cypress yielding the least color. Stronger concentrations become dark brown or black, with cypress and pine showing lighter shades than the other woods.

Saturated, Filtered Lime Water — This becomes pale yellow with four of the woods and light brown with oak and redwood.

Five Per Cent Bleaching Powder Suspension—This becomes pale yellow from all of the woods except cypress, which yields no color.

Sodium Sulphide — This strongly alkaline salt acts very similar to caustic soda, assuming pronounced shades of brown very quickly from all of the woods.

C—Colors Extracted by Cold Salt Solutions

Sodium Carbonate — A 5% solution becomes faintly yellow with cypress and much deeper in color with the other woods. All of the six woods, therefore, can be said to yield color to any liquid which is alkaline in reaction but cypress is better than the other woods.

Sodium Bisulphite — A 10% solution is colored pale yellow by all of the woods; with oak, however, quite a precipitate is formed and the color of the solution changes to grayish-black.

Sodium Chloride—A 10% solution becomes yellow or light brown when in contact with all of the woods except fir and pine, which yield no color to the liquid.

Calcium Chloride — 10% and 25% solutions of this salt remain uncolored by all of the woods except oak and redwood. Maple shows a trace of color in the 25% solution, but not in the 10% dilution.

D—Colors Extracted by Organic Liquids

Turpentine is given a slight yellow tint by all of the woods, but linseed oil and distilled cotton-seed oil fatty acids remain unaltered in color.

E—Colors Extracted by Hot Liquids

A hot liquid naturally extracts more color from a wood than does the same liquid when cold, and only

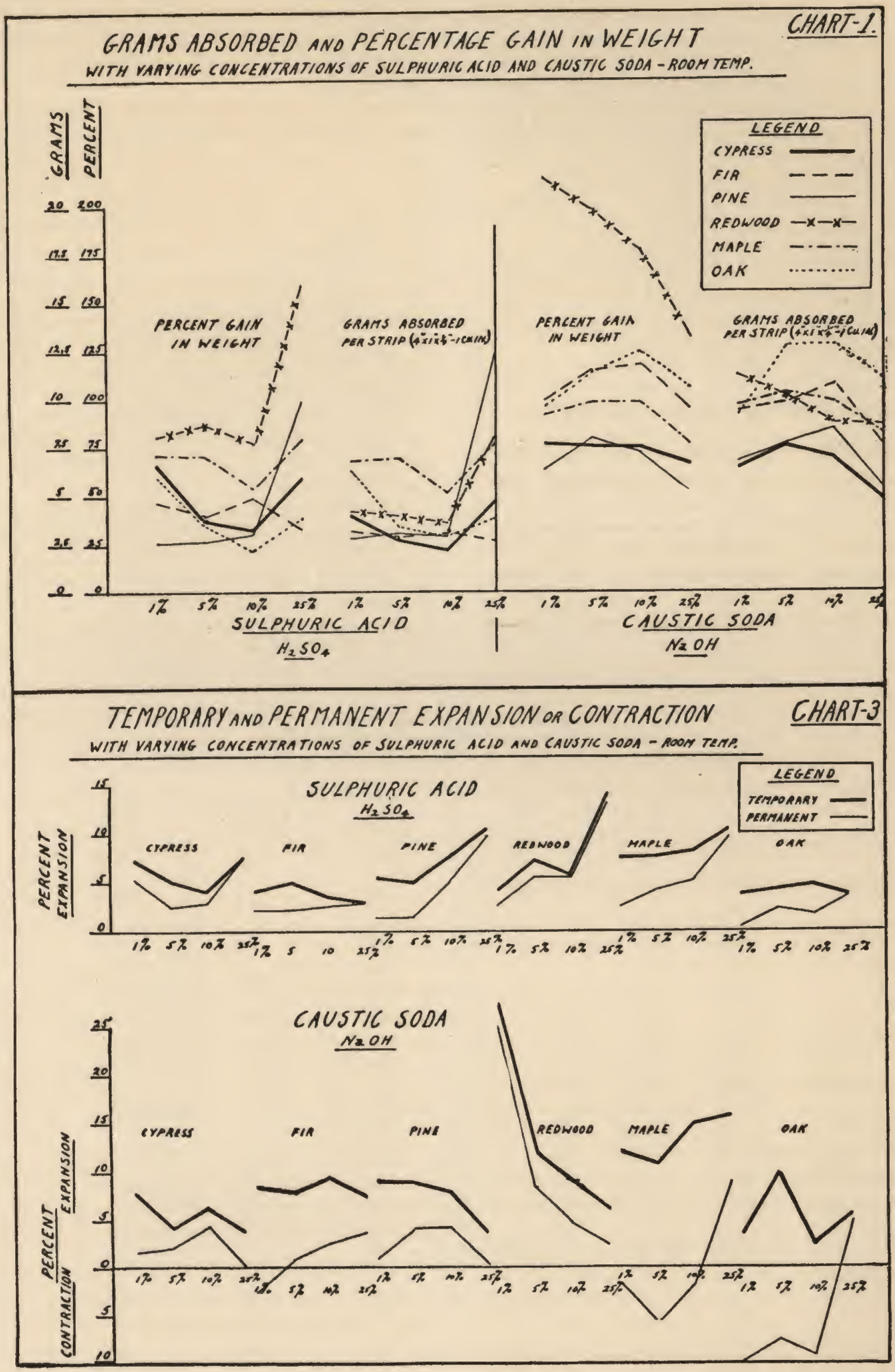


CHART-1.
GRAMS ABSORBED AND PERCENTAGE GAIN IN WEIGHT
WITH VARYING CONCENTRATIONS OF SULPHURIC ACID AND CAUSTIC SODA - ROOM TEMP.
GRAMS
PERCENT
LEGEND
CYPRESS
FIR
PINE
REDWOOD
MAPLE
OAK
PERCENT GAIN IN WEIGHT
GRAMS ABSORBED PER STRIP
SULPHURIC ACID
H_2SO_4
CAUSTIC SODA
$Na OH$
CHART-3
TEMPORARY AND PERMANENT EXPANSION OR CONTRACTION
WITH VARYING CONCENTRATIONS OF SULPHURIC ACID AND CAUSTIC SODA - ROOM TEMP.
LEGEND
TEMPORARY
PERMANENT
SULPHURIC ACID
H_2SO_4
PERCENT EXPANSION
CYPRESS
FIR
PINE
REDWOOD
MAPLE
OAK
CAUSTIC SODA
$Na OH$
PERCENT EXPANSION
CONTRACTION

a few comparisons of colors extracted from hot and cold solutions of the same strength need be mentioned here.

5% and 10% solutions of hydrochloric and sulphuric acids uncolored by cypress, fir, maple and pine when in the cold, assume a light yellow or brown color when boiled with these woods. Boiling 1% caustic soda becomes opaque black when in contact with fir, oak and redwood, the other three woods yield light brown colors. The stronger solutions, of course, are colored much more deeply.

Turpentine, at 150°C, is rendered very slightly yellow by all of the woods, but hardly more so than at room temperatures. The hot linseed oil (temperature about 160°C) is not appreciably darkened by any of the woods. The hot distilled cotton-seed oil fatty acids is very slightly darkened by the oak and the redwood, but not by the other woods.

II—QUANTITY OF LIQUID ABSORBED

The amount of liquid absorbed by the wood after one week's immersion at room temperature and after 8 hours in the boiling solution has been expressed in two ways, First, as the percentage of the original weight of the wood and, Second, as the grams absorbed per strip of wood, *i. e.*, per cubic inch.

There is a wide difference in the weight of equal volume of the woods used in these tests, and an actual percentage gain in weight in two woods by no means denotes an equal absorptive power. A high absorption of a liquid which has destructive action upon the wood evidently will hasten the disintegration of the latter, which would not proceed nearly so rapidly were the absorbent powers of the wood not so great.

For this reason the weight of solution absorbed per strip or cubic inch is more significant, and is more of a measure of the absorptive powers of the wood than is the percentage gain in weight. To illustrate the different significance of percentage absorbed and weight absorbed, the results for redwood will serve as an example. This wood, with all of the 37 concentrations of the 16 liquids used in this work, shows a very much greater percentage gain in weight than any of the other woods, although in the great majority of cases it is maple which really absorbs the most per cubic inch, as will be brought out in the tables and charts.

The amount of liquid absorbed at room temperature was obtained after one week's immersion. The solutions which were used in this study are shown in Table No. 4.

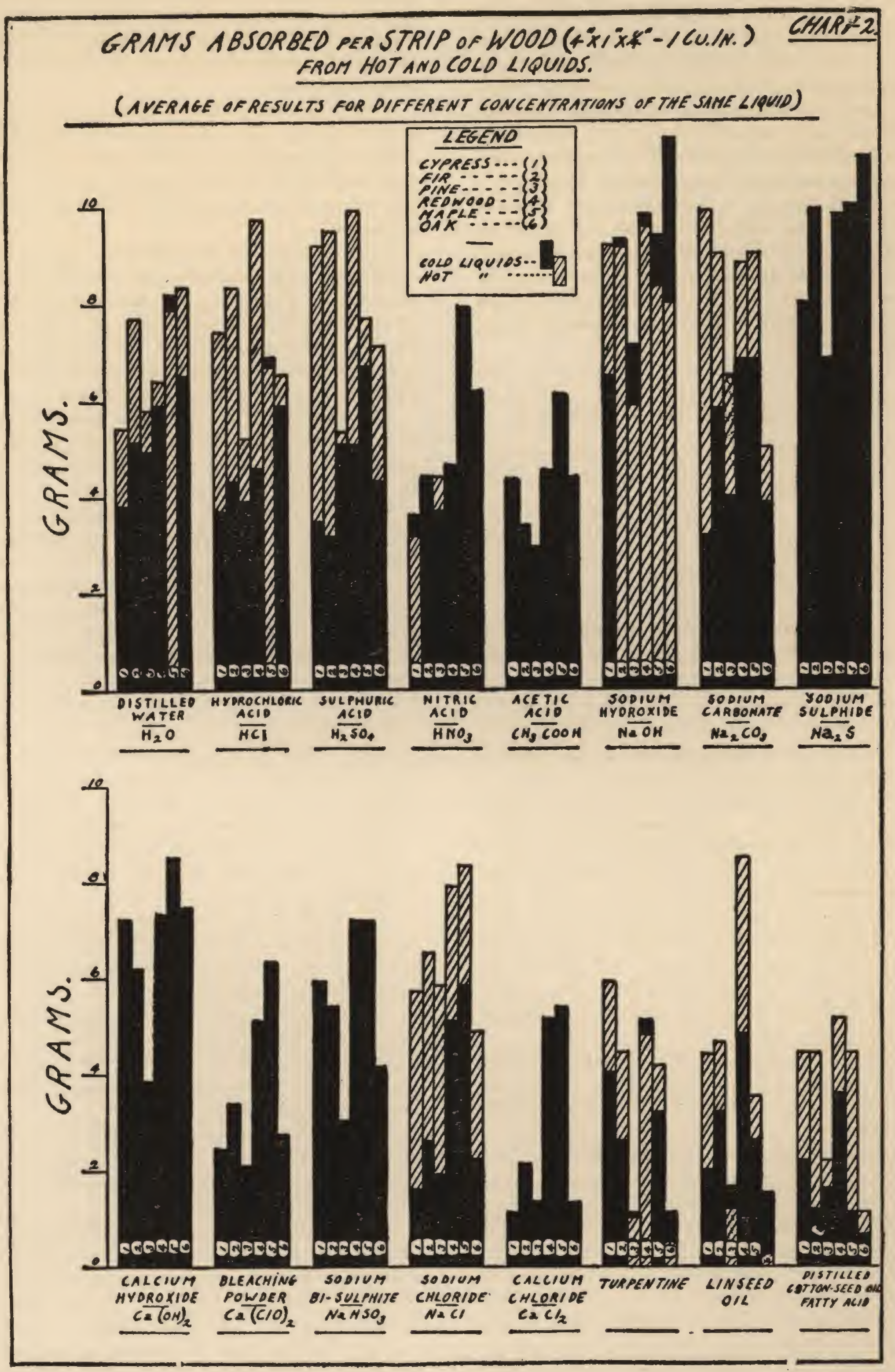
For absorption of hot liquids, the wood strips were weighed immediately after removal from the hot fluid, in which they had been heated for a total period of 8 hours. With the aqueous solutions the temperature obtained was that of their boiling points, which varied from slightly above 100°C to about 110°C for the more concentrated liquids. The

TABLE No. II.

Grams absorbed per strip of wood
(4" x 1" x ¼' 1 cu. in.) from cold and hot liquids
(Averages of results for different concentrations of the same solution.)

		(1) Cypress	(2) Fir	(3) Pine	(4) Redwood	(5) Maple	(6) Oak
H_2O (Water)	cold	3.8	5.1	4.9	5.9	8.2	6.5
	hot	5.4	7.7	5.8	6.4	7.9	8.3
HCl (Hydrochloric Acid)	cold	3.7	4.3	3.9	4.6	6.8	5.9
	hot	7.4	8.3	5.2	9.7	6.7	6.5
H_2SO_4 (Sulphuric Acid)	cold	3.5	3.2	5.1	5.1	6.7	4.3
	hot	9.2	9.5	5.3	9.9	7.7	7.1
HNO_3 (Nitric Acid)	cold	3.6	4.4	3.7	4.6	7.9	6.2
	hot	3.2	(x)	4.4	(x)	(x)	(x)
CH_3COOH (Acetic Acid)	cold	4.3	3.4	2.9	4.5	6.1	4.4
NaOH (Sodium Hydroxide)	cold	6.5	9.3	7.1	9.8	9.4	11.4
	hot	9.2	9.2	5.9	9.6	8.3	8.0
Na_2CO_3 (Sodium Carbonate)	cold	3.2	5.8	4.0	6.8	6.8	3.9
	hot	9.9	9.0	6.5	8.8	9.0	5.0
Na_2S (Sodium Sulphide)	cold	8.0	9.9	6.8	9.8	10.0	11.0
$Ca(OH)_2$ (Calcium Hydroxide)	cold	7.2	6.2	3.8	7.4	8.5	7.5
$Ca(ClO)_2$ (Bleaching Powder)	cold	2.4	3.3	2.1	5.1	6.3	2.7
$NaHSO_3$ (Sodium Bi-Sulphite)	cold	5.9	5.4	3.0	7.2	7.2	4.1
NaCl (Sodium Chloride)	cold	1.6	2.6	1.9	5.1	5.8	2.2
	hot	5.7	6.5	5.8	7.9	8.3	4.8
$CaCl_2$ (Calcium Chloride)	cold	1.1	2.1	1.3	5.2	5.4	1.3
Turpentine	cold	4.0	2.6	1.1	5.1	3.1	1.1
	hot	5.9	4.4	1.1	4.8	4.1	0.5
Linseed Oil	cold	2.0	3.2	1.6	4.8	2.6	1.5
	hot	4.4	4.6	1.1	8.5	3.5	0.2
Cottonseed Oil Fatty Acids	cold	2.1	1.2	1.6	3.6	1.1	0.7
	hot	4.4	4.4	2.2	5.2	4.4	1.1

(x) Wood too much disintegrated to weigh.


GRAMS ABSORBED PER STRIP OF WOOD (4"x1"x¼" - 1 Cu. In.)
FROM HOT AND COLD LIQUIDS.
CHART #2
(AVERAGE OF RESULTS FOR DIFFERENT CONCENTRATIONS OF THE SAME LIQUID)
LEGEND
CYPRESS --- (1)
FIR ------ (2)
PINE ----- (3)
REDWOOD -- (4)
MAPLE ---- (5)
OAK ------ (6)
COLD LIQUIDS --
HOT " ------
GRAMS.
DISTILLED WATER H_2O
HYDROCHLORIC ACID HCl
SULPHURIC ACID H_2SO_4
NITRIC ACID HNO_3
ACETIC ACID CH_3COOH
SODIUM HYDROXIDE NaOH
SODIUM CARBONATE Na_2CO_3
SODIUM SULPHIDE Na_2S
GRAMS.
CALCIUM HYDROXIDE $Ca(OH)_2$
BLEACHING POWDER $Ca(ClO)_2$
SODIUM BI-SULPHITE $NaHSO_3$
SODIUM CHLORIDE NaCl
CALCIUM CHLORIDE $CaCl_2$
TURPENTINE
LINSEED OIL
DISTILLED COTTON-SEED OIL FATTY ACID

turpentine, linseed oil and cotton seed oil fatty acids reached temperatures of 140 to 165°C.

DISCUSSION OF RESULTS—The amounts absorbed by any one wood from different concentrations of the same chemical fluctuated irregularly, and many graphic charts were prepared in an attempt to formulate some general rule which would express the behavior of the wood, as regards absorption, when the strength of the solution was altered. It was expected that the amounts absorbed would either increase or decrease as the strength of the solution was increased, and that the different woods, in most instances, would act similarly, but the results were disappointing. As an illustration of the irregularity of the absorption results, we may discuss the data obtained with sulphuric acid and caustic soda, shown in Chart No. 1.

In this chart it will be seen that with cypress and oak the percentage gain in weight due to absorption of sulphuric acid decreases rapidly as the concentration of the acid is increased to 10%, whereas redwood, maple and pine absorb practically the same in 1% and 5% sulphuric acid.

The absorption of the redwood and maple then decreases as we approach the 10% concentration (similar to the decrease shown by cypress and oak), but fir shows increased absorptive powers within this zone, while that of pine is changed but little. Redwood, pine and maple show the highest absorption when in the 25% solution, while fir shows less absorption than with the weaker solutions.

The absorption curves for the six woods in caustic soda solution also are not similar. While cypress absorbs about the same amount from 1%, 5% and 10% solutions of this chemical and then suffers a decrease in absorptive capacity, fir, maple, oak and pine act quite differently. The absorption by these woods increases as the strength of solution increases, reaching a peak at the 10% soda solution for the first three woods and at 5% for the pine. The redwood curve, moreover, is entirely dissimilar to that of the other woods, showing a precipitous drop from the 1% to the 25% concentrations. All the woods, with the exception of oak, are alike, however, in that the least absorption is obtained with the strongest concentration of the alkali.

The foregoing discussion, with only minor modifications, holds good if based upon the grams absorbed per cubic inch instead of upon the percentage gain in weight.

Similar peculiarities were shown to exist with hot solutions and with other chemicals in solutions of different concentration, but these will not be taken up in this paper. Suffice it to say that these differences for general purposes are of minor importance; they are differences of degree only. We have found that they may be smoothed over and the data simplified, without any loss in significance, if the results for the various concentrations of one chemical are averaged. A comparison of these averages then reveals the difference in absorptive capacity of the woods in which we are interested.

Table No. 2 shows the average number of grams absorbed per strip (cubic inch) in both hot and cold liquids. These results are best studied by graphic charts. Chart No. 2 has been prepared from the figures shown in Table No. 2 and Chart No. 4 from those displayed in Table No. 3. The charts are self-explanatory. A study of this data reveals the following facts:

(1) All of the woods absorbed varying amounts of the liquid in which they were immersed. The lowest absorption was 0.2 gram of hot linseed-oil per cubic inch, by oak, and the same wood showed the highest absorption 11.4 grams of NaOH per cubic inch.

(2) The weight of cold water, hydrochloric acid and nitric acid, absorbed per cubic inch is greatest in the case of maple and least with cypress, the order of absorption being maple, oak, redwood, fir, pine, cypress. Practically the same weight of each three liquids is absorbed by any one wood; the remarkable similarity of the water, HCl and HNO_3 diagrams in chart No. 2 illustrates this graphically.

(3) With H_2SO_4 and acetic acid maple still stands out with the highest absorptive power, but, unlike the water HCl and HNO_3 results, we find cypress absorbing more than fir, redwood more than oak, and pine equaling redwood in absorption of sulphuric acid.

(4) Sodium sulphide, due to hydrolysis, gives an intensely alkaline solution, and very similar results upon all the woods are obtained with this chemical and with caustic soda. Oak and not maple, absorbs the most of these two strong alkalis per cubic inch. Maple and redwood absorb about the same amounts, with fir taking up only a slightly lesser amount. The weight of the alkali solutions absorbed by all of the woods is considerably greater than the quantities of water, acids, salt and organic liquids, which are absorbed, as will be seen from the chart.

(5) Lime water, also, is absorbed to a greater extent than acids and salts by all the woods with the exception of pine.

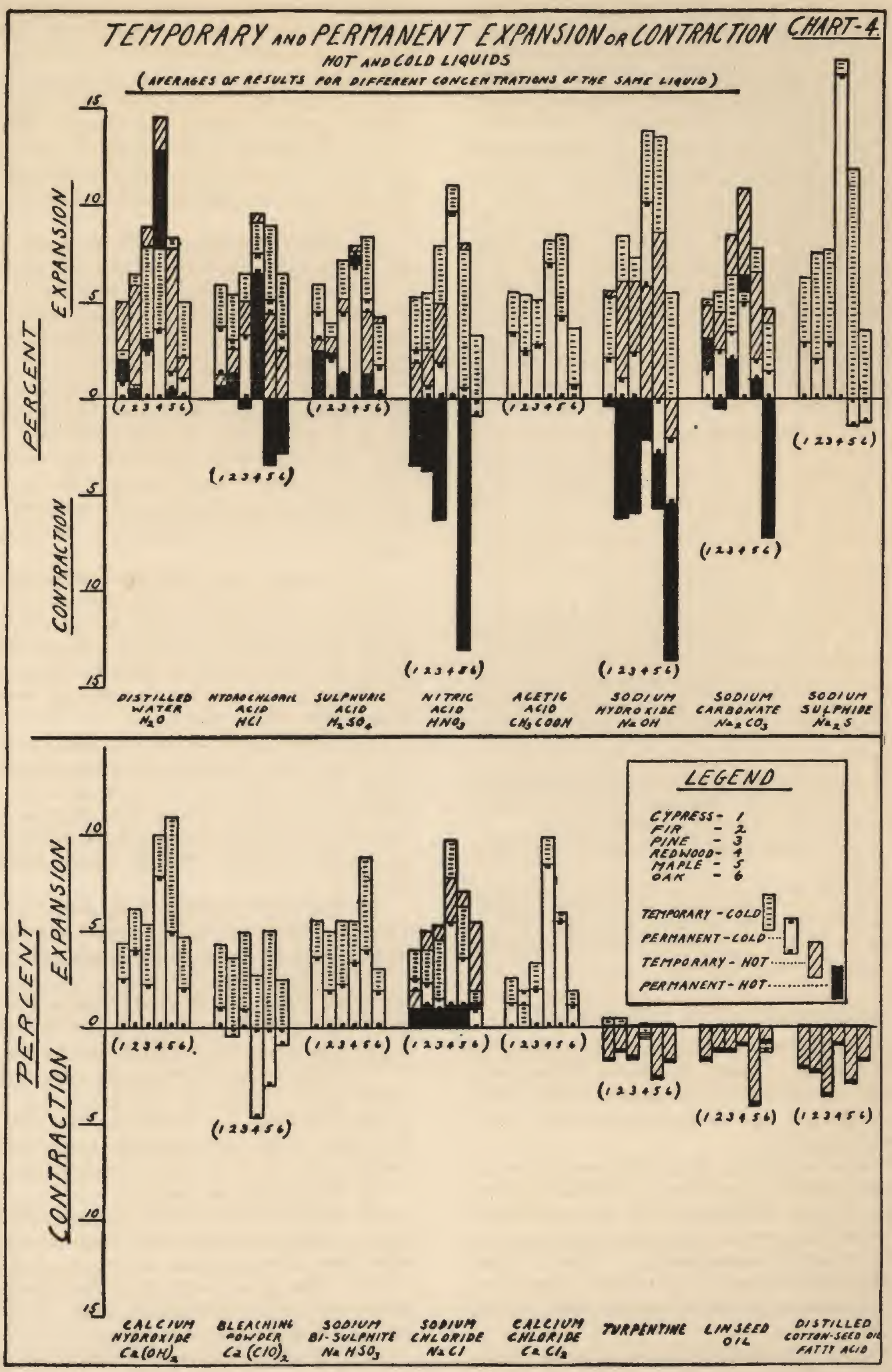
(6) With bleaching powder and Na_2CO_3, maple, redwood and fir show the highest absorptions, while cypress, oak and pine show lesser and, roughly, the same absorptive capacity.

(7) Cypress, which shows comparatively low absorptions of acids and salts, absorbs an unusually large amount of $NaHSO_3$, 5.9 grams per cubic inch. Maple and redwood, however, absorb greater amounts than the other woods.

(8) With the neutral salts, NaCl and $CaCl_2$, the absorptions for any one wood are roughly, quite similar, the NaCl being absorbed to a somewhat larger extent than the $CaCl_2$.

(9) In all of the three organic liquids maple surrenders its high absorptive capacities to redwood, while oak absorbs least. Cypress shows higher absorptive capacities than we would expect from the results with the other chemicals.

(10) Maple has been shown to absorb more grams per cubic inch from water, acids, weak alkalis and salts than do the other woods. Redwood, however, on account of its lightness, always shows the highest percentage gain in weight, without exception.


TEMPORARY AND PERMANENT EXPANSION OR CONTRACTION
CHART-4.
HOT AND COLD LIQUIDS
(AVERAGES OF RESULTS FOR DIFFERENT CONCENTRATIONS OF THE SAME LIQUID)
PERCENT
EXPANSION
CONTRACTION
15
10
5
0
5
10
15
(1 2 3 4 5 6)
DISTILLED WATER H_2O
HYDROCHLORIC ACID HCl
SULPHURIC ACID H_2SO_4
NITRIC ACID HNO_3
ACETIC ACID CH_3COOH
SODIUM HYDROXIDE $NaOH$
SODIUM CARBONATE Na_2CO_3
SODIUM SULPHIDE Na_2S
CALCIUM HYDROXIDE $Ca(OH)_2$
BLEACHING POWDER $Ca(ClO)_2$
SODIUM BI-SULPHITE $NaHSO_3$
SODIUM CHLORIDE $NaCl$
CALCIUM CHLORIDE $CaCl_2$
TURPENTINE
LINSEED OIL
DISTILLED COTTON-SEED OIL FATTY ACID
LEGEND
CYPRESS - 1
FIR - 2
PINE - 3
REDWOOD - 4
MAPLE - 5
OAK - 6
TEMPORARY - COLD
PERMANENT - COLD
TEMPORARY - HOT
PERMANENT - HOT

(11) The lines in the charts which represent the absorption from hot liquids do not parallel those of the cold fluids. In practically all cases, however, water, the acids, salts and the three organic fluids were absorbed to a greater extent when hot. Sodium hydroxide is unusual in the respect that all of the woods absorb more from cold than from hot solutions of this chemical.

(12) Another peculiarity of the hot tests is seen in the very low amounts of hot turpentine and hot linseed oil which are absorbed by oak, less than is absorbed by the cold liquid. It will be seen in the chart that oak and pine absorb much smaller amounts from the three organic liquids, when hot, than do the other woods. The low absorption of hot linseed oil, hot turpentine and hot distilled fatty acid may be partially due to the loss of moisture, naturally contained in the wood, at the high temperatures employed.

Conclusions

(a) There seems to be no general rule governing the amount absorbed by wood from different concentrations of the same chemical.

(b) With all the liquids redwood shows the greatest absorption, when this is expressed as a percentage of the original weight of the wood.

(c) When expressed as grams absorbed per cubic inch, however, maple has the greatest absorptive capacity toward water, acids, weak alkalis and salts. In strong alkali solution oak has the greatest absorptive capacity; in the three organic liquids, redwood ranks first while oak has comparatively low absorptive properties.

(d) Each of the woods absorb acids to about the same extent to which it absorbs water, but strong alkalis are taken up to a much greater extent.

(e) Hot water is absorbed much more freely than any other liquid.

(f) Usually the hot liquids are absorbed in greater amounts than the cold fluids, but caustic soda is an exception to this, more being absorbed from the cold than from the hot solution.

III—EXPANSION AND SHRINKAGE

The temporary and permanent expansions, as defined earlier in this paper, also show irregularities in magnitude for different strengths of the same chemical in solution, just as was found when studying the absorption data.

With the acid solutions, the difference between the temporary and the permanent swelling is greatest with the weaker dilutions, and the two determinations closely approach and often equal one another at the stronger concentrations. This is illustrated graphically in Chart No. 3 which shows the curves given by the six woods in various dilutions of sulphuric acid.

With the salts and alkalis, however, such a relationship between the temporary and permanent swelling was not clearly marked. With caustic soda the temporary and permanent expansion for five of the woods, remained well separated at the stronger concentrations, although they were almost identical in the case of oak in 25% NaOH. This wood suffered contraction, after air-drying, in the weaker solutions of this alkali. The caustic soda curves are also shown in Chart No. 3.

In studying the data, the results for various dilutions of the same chemical were averaged as was done with the absorption figures. These average results are shown in Table No. 3. When shrinkage occurred it was expressed as a negative expansion. Chart No. 4 is constructed from the figures shown in this table.

Discussion of Results — A study of the results for expansion and contraction reveals:

(1) All woods expand, or "swell," when exposed to cold aqueous solutions. There is but little change in dimensions, however, in linseed oil, turpentine, or cottonseed oil fatty acids.

(2) When the expanded wood is removed from the solutions and allowed to dry in the air for one week, considerable of this temporary expansion is lost. In most cases, however, the contraction during air drying is only partial; the air-dried wood very seldom goes back to its original dimensions. There is in most instances, a "permanent expansion."

(3) In some cases the wood, which has expanded while in the liquid, will shrink far beyond its original dimensions, after being air-dried. Thus nitric acid, caustic soda and sodium sulphide force both oak and maple to shrink; while redwood, in addition to oak and maple, shrinks when in a solution of bleaching powder.

(4) With all solutions the temporary expansion may either be greater or less than that of the same wood in water, but the permanent expansion is almost invariably greater than that in water, except with those solutions which have marked contractile properties (HNO_3, NaOH, Na_2S, Bleaching Powder).

(5) For any wood the temporary swellings in the aqueous solutions do not differ greatly in magnitude, but the permanent expansions vary widely.

(6) Redwood swells more under the influence of nitric acid than when acted upon by the other acids, but with the other woods nitric acid produces the least expansion, and actually causes oak to contract.

(7) NaOH and Na_2S produce no unusual expansions with cypress, fir and pine, but cause a pronounced shrinkage in maple and oak. Redwood, however, shows an enormous expansion with these chemicals, just as it did with nitric acid.

(8) Bleaching powder, in addition to the above chemicals, has contractile properties, causing shrinkage in redwood, maple, oak and fir, and permitting only limited expansions in cypress and pine.

(9) With practically all of the solutions redwood shows the greatest swellings, and oak the least. The latter wood often is shrunken.

(10) With liquids above 100°C the expansion is less, in most cases, than with liquids at room temperature, and pronounced shrinkages are frequently encountered.

(11) The tendency of hot liquids to produce

shrinkage is quite marked (as high as 21% in the case of oak in hot 5% NaOH). These contractions do not occur, however, while the wood is in the hot fluid, but only after it has undergone drying in the air. Oak is the only exception to this.

(12) Cypress and pine, which were never shrunken by cold liquids, showed contractions with hot NaOH and HNO_3, but only after being air-dried. Pine also contracted with hot HCl solutions.

(13) With the hot solutions maple and oak were contracted more frequently and to a greater extent than the other woods.

(14) With the hot aqueous solutions the shrinkages appeared only after the wood had been removed from the solution and had dried in the air. With the organic liquids, however, the temporary and permanent expansions were identical, and always negative. In other words with these substances the shrinkage took place while the wood was in the hot liquid, and subsequent air-drying caused no changes in dimensions.

Conclusions

(a) All woods expand in cold aqueous solutions. This increase in dimensions is partially lost when the wet wood dries in the air. Some woods, with nitric acid and the alkalis, show shrinkages after drying. With hot solutions there is a marked tendency toward shrinkage, but usually this does not occur until after the wood has dried. This tendency is least shown by cypress, pine and redwood.

(b) The cold organic liquids produce neither swelling nor shrinkage, but the hot liquids cause a shrinkage in all woods, and this takes place while the woods are still in the fluid.

(c) In cold aqueous solutions the permanent swelling is greater than in water.

(d) Redwood shows the greatest expansion and oak the least. Oak and maple show shrinkages very frequently. Cypress, pine and fir show intermediate expansions. Cypress and pine never show shrinkage in cold aqueous solutions, and only seldom in the hot solutions.

TABLE No. III.

Temporary and Permanent Expansion of Different Woods in Hot and Cold Liquid.
(Averages for different concentrations of the same solution.)

		(1) Cypress		(2) Fir		(3) Pine		(4) Redwood		(5) Maple		(6) Oak	
		Temp.	Perm.	Temp.	Perm.	Temp.	Perm.	Temp.	Perm.	Temp.	Perm.	Temp.	Perm.
H_2O (Water)	cold	2.5	1.0	6.5	0.5	8.0	2.5	8.0	3.5	8.5	1.5	5.0	1.0
	hot	5.0	2.0	6.0	0.5	9.0	3.0	14.5	13.0	8.0	0.5	2.0	0.0
HCl (Hydrochloric Acid)	cold	5.8	3.8	5.4	3.1	6.5	3.3	9.1	7.6	9.0	5.1	6.5	3.4
	hot	1.3	0.7	2.7	1.3	5.0	−0.4	9.5	6.5	4.6	−3.4	2.5	−2.9
H_2SO_4 (Sulphuric Acid)	cold	5.8	4.5	3.9	2.4	7.1	4.4	7.6	6.9	8.4	5.2	3.9	1.8
	hot	3.1	2.5	3.1	2.4	5.2	1.4	7.8	7.6	4.5	1.3	4.0	0.1
HNO_3 (Nitric Acid)	cold	5.3	2.5	5.5	0.8	7.3	2.0	11.8	9.7	7.7	0.5	3.3	−1.3
	hot	1.8	−3.4	2.5	−3.7	5.0	−6.3	(x)	(x)	8.0	−12.9	(x)	(x)
CH_3COOH (Acetic Acid)	cold	5.4	3.5	5.3	2.5	5.1	2.8	8.3	7.0	8.6	4.4	3.7	1.5
NaOH (Sodium Hydroxide)	cold	5.3	1.9	8.4	1.1	7.4	2.4	13.6	10.1	13.0	−2.8	5.4	−5.3
	hot	5.5	−0.2	6.4	−6.5	6.4	−6.0	5.9	−2.1	8.5	−5.6	−2.0	−13.5
Na_2CO_3 (Sodium Carbonate)	cold	5.0	1.5	5.5	2.5	6.5	3.5	5.5	5.0	7.8	2.0	3.9	1.3
	hot	5.0	3.0	4.5	−0.4	8.5	2.0	10.8	6.5	6.7	1.0	4.5	−7.2
Na_2S (Sodium Sulphide)	cold	6.8	3.0	7.8	2.2	8.0	2.0	17.5	16.8	11.8	−1.3	3.5	−1.2
$Ca(OH)_2$ (Calcium Hydroxide)	cold	4.3	2.5	6.0	4.0	5.5	2.3	10.0	8.0	11.0	5.0	4.7	2.0
$Ca(ClO)_2$ (Bleaching Powder)	cold	4.2	1.0	3.5	−0.4	5.0	1.0	2.7	−4.7	5.0	−3.0	2.5	−0.8
$NaHSO_3$ (Sodium Bi-Sulphite)	cold	5.5	3.5	5.0	1.8	5.5	2.2	5.5	3.3	8.7	4.0	3.0	1.8
NaCl (Sodium Chloride)	cold	4.0	2.5	4.0	2.2	4.5	1.5	9.5	5.5	6.3	3.5	1.8	1.0
	hot	1.8	1.0	5.0	1.1	5.3	1.0	7.7	1.1	7.0	1.1	5.3	1.1
$CaCl_2$ (Calcium Chloride)	cold	2.5	1.3	1.2	1.8	3.2	2.0	9.8	8.5	6.0	5.5	1.8	1.2
Turpentine	cold	0.5	0.0	0.5	0.0	0.0	0.0	−0.5	−0.5	0.0	0.0	0.0	0.0
	hot	−1.7	−1.7	−2.0	−2.0	−1.6	−1.6	−0.5	−0.5	−2.7	−2.7	−1.7	−1.7
Linseed Oil	cold	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	−1.2	−1.2
	hot	−1.8	−1.8	−1.2	−1.2	−1.2	−1.2	−0.9	−0.9	−4.0	−4.0	−0.8	−0.8
Cottonseed Oil Fatty	cold	0.0	0.0	0. 0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Acids	hot	−2.1	−2.1	−2.4	−2.4	−3.6	−3.6	−0.9	−0.9	−2.0	−2.9	−1.7	−1.7

NOTE—A negative sign indicates contraction or shrinkage. (x) Wood too much disintegrated to caliper.

IV—OTHER PHYSICAL EFFECTS OF CHEMICALS UPON WOOD

The physical condition of the test strips after one month in the cold liquids and after an eight-hour exposure to the hot fluids is shown in Table No. 4.

The following abbreviations were used:

SS—slightly soft.
S—soft.
VS—very soft.
VH—very hard.
SB—slightly brittle.
B—brittle.
VB—very brittle.
P—pliable.
SP—slightly pliable.
Sh—noticeably shrunken.
Ex—noticeably expanded.
Cl—cracked lengthwise.
W—warped.
Di—considerably distorted.
GR—grain raised or roughened.
FZ—covered with downy "fuzz."
CH—charred.
Shd—shredded, easily picked apart.

In Table No. 4 a dash indicates no noticeable action upon the wood, and, where the test was made at room temperature only, an unfilled space is left in the hot column. The results were recorded after the strips had dried in the air for one week after their removal from the liquids. There was very little difference in the condition of the wood just when removed from the liquid and after the additional air drying, except that in some cases a slight pliability in the wet wood would disappear after drying, a slight brittleness being noted.

Table No. 4 reveals the action of the different chemicals upon each of the woods very clearly. Slight softness (SS) and a roughening of the grain (GR) probably have little significance and should not be taken as indicating unfitness of the wood. The other terms, however, are demerits which lessen the adaptability of the wood for use with chemical solutions. To summarize the information shows in this table—

(1) Acetic acid, even in glacial concentration, has no effect upon any of the woods.

(2) Redwood is rendered brittle even by 5% HCl, and maple and oak are similarly affected by the 25% acid, but this strength has no detrimental effect upon cypress, fir and pine. Hydrochloric acid in 50% concentrations, however, injures all of the woods except pine.

The concentrated acid is exceedingly destructive to all woods, and especially so to oak and maple.

(3) Even 1% H_2SO_4 produces brittleness in redwood, but 5% has little effect upon other woods. Ten percent H_2SO_4 effects oak and maple and causes softness in fir. Cypress and pine, however, are unacted upon, and these woods are not much affected, outside of slight brittleness in cypress, by the 25% acid.

(4) Redwood becomes very soft in 5% HNO_3, and oak and maple are injured by 10% HNO_3; this, however, has no serious action upon cypress, fir and pine. Twenty-five per cent nitric acid has pronounced action upon all of the woods; maple and oak being considerably shrunken by this chemical.

(5) Maple, oak and redwood are attacked to a remarkable extent by 1% NaOH, although the other woods withstand the action of 10% alkali. Pine is the only wood not affected by 25% NaOH, which renders the other woods pliable.

(6) Sodium sulphide up to 20% concentration is destructive only to oak and redwood.

(7) Oak, maple and redwood are not adapted for use with bleaching powder since they are either shrunken or rendered soft or pliable. Cypress, fir and pine seem to be little affected, except for the formation of a surface film of fine fibers. This occurred with all of the woods.

(8) A slight brittleness appears in redwood, when soaked in common salt solution, but the other woods are unaffected; and all of the woods show no effects from $NaHSO_3$, lime water, $CaCl_2$ or from the three organic liquids.

(9) Hot liquids naturally have a more powerful action than the cold fluids.

(10) Boiling 25% solutions of HCl and H_2SO_4 ruin all of the woods, redwood being completely charred by these solutions.

(11) Boiling 5% HNO_3 injures all of the woods. In the hot 10% HNO_3 all the strips were shredded into long fibers.

(12) Cypress stands up well in boiling NaOH up to 25% concentration. Pine is not noticeably attacked until the concentration reaches 10%. The other four woods were harmed considerably even by hot 1% solutions.

(13) Hot Na_2CO_3 shrinks oak and softens redwood, and hot NaCl renders the latter wood brittle, but the other woods show no visible effects from these salts.

(14) No action upon any of the woods was shown by the hot organic liquids.

Conclusions

(a) Of all the chemicals used in these experiments, nitric acid and caustic soda are the most detrimental towards wood. The alkali and the stronger dilutions of nitric acid have a tendency to cause shrinkage, especially when heated.

(b) There is always one wood (and often more) which is able to resist the action of the other chemicals, at least in moderate concentrations.

(c) We can obtain a general idea of the relative fitness of the six woods from the number of instances in which each of them was detrimentally affected. Of the thirty-eight liquids used, the number which noticeably affected the different woods at room temperature (disregarding slight softness and roughening of grain) was as follows—pine 4, cypress 7, fir 8, maple 13, oak 15, redwood 22.

PROTECTIVE COATINGS

Asphalt and coal-tar pitches are sometimes used as a protective coating upon woods which are to be exposed to the action of corrosive liquids. These products may be either solids, which are liquefied

TABLE IV.

PHYSICAL EFFECTS OF CHEMICALS UPON WOOD
(After one month in cold and eight hours in boiling liquids)

		Cypress		Fir		Pine		Redwood		Maple		Oak	
		Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot
H_2O (Water)		......	....	......	....	....	....	....	....	....	....	....	....
CH_3COOH ((Acetic Acid)	5%	......	....	......	....	....	....	....	....	....	....	....	....
	25%	......	....	......	....	....	....	SS	....	....	....	....	....
	50%	SS	....	SS	....	....	....	SS	....	....	....	....	....
	glacial	SS	....	SS	....	....	....	SS	....	....	....	....	....
HCl (Hydrochloric Acid)	5%	......	....	......	S	....	....	SS, VB	VS, B	....	SS	....	....
	10%	SS	SS	SS	S	....	SS	SS, VB	VS, B	....	S	....	SS
	25%	SS	VS, VB	SS	VS, VB	SS	S	SS, VB	VS, VB, Ch	S, B	VS, VB	SS, SB	VS, VB
	50%	S, Cl, SB	....	SS, Cl	....	SS	....	S, VB	....	S, B	....	S, B	....
	conc. (a)	VS, B, Cl	....	VS, B, GR	....	VS, B, Cl	....	VS, VB	....	VS, B, Sh, Cl	....	VS, B, Di, Ex, Cl	....
H_2SO_4 (Sulphuric Acid)	1%	SS	S	SS	S	....	....	SS, B	VS	....	SS	....	W
	5%	SS	S	SS	S	....	SS	VS, B	VS, B	....	S	SS	SS
	10%	SS	VS, P	S	S	SS	SS	VS, B	VS, VB	SS, B	S	SS, SB	SS
	25%	SS, SB	VS, VB	S, B	VS, VB	SS	VS, VB	VS, VB	VS, VB, Ch	VS, VB	VS, VB	SS, B	VS. VB
HNO_3 (Nitric Acid)	5%	......	S	SS	VS	....	S, Shd	VS, VB	VS, VB	SS	VS, Shd	SS, GR	S, Cl, Shd
	10%	......	VS, Shd	SS	VS, Shd	SS	S, Shd	VS, VB	VS, VB, Cl, Shd	SS, SB	VS, Shd	S, B, GR, Sh	S, Cl, Shd
	25%	S, B	Shd, VS	VS, B	VS, Shd	SS, B, Cl	S, Shd	VS, VB	VS, VB, Cl, Shd	S, BB, Sh	VS, Shd	VS, VB, GR, Sh, Cl	S, Cl, Shd
NaOH (Sodium Hydroxide)	1%	......	SS	......	Sh, GR	....	....	VS, W, SB, GR	S	Cl	Sh	Sh, Vh, Di	Vh, Sh, Di
	5%	......	SS	SS	Sh, GR	....	....	VS, SB, GR	S	Sh	Sh	Sh, VH, Di, GR	Vh, Sh, Di
	10%	......	SS	SS, GR	Sh, GR	SS	VH, Sh, Di, GR	VS, GR, P	S, Sh, Di, GR	Sh, GR, W	....	Sh, Vh, Di, GR, W, P	Vh, Sh, Di, GR
	25%	SS, P	SS	SS, GR, P	GR	SS	Vh, GR, W	SS, GR, P	S, Sh, Di, GR, B	Sh, GR, SS, P	W, GR	SS, GR, W. P	WH, GR
Na_2S (Sodium Sulphide)	5%	SS	....	SS	....	....	....	S, P, B	....	....	....	SS, GR, P	....
	20%	SS	....	SS	....	....	....	S, P, B	....	....	....	SS, GR, P	....
$NaHSO_3$ (Sodium Bi-Sulphite)	10%	......	....	......	....	....	....	SS	....	....	....	....	....
	25%	......	....	......	....	....	....	SS	....	....	....	....	....
Na_2CO_3 (Sodium Carbonate)	5%	......	SS	......	GR	....	....	....	S	....	....	....	Sh, GR
	20%	......	SS	......	....	GR	....	....	S	....	....	....	Sh, GR
$Ca(OH)_2$ (Calcium Hydroxide)	filtered	......	....	......	....	....	....	GR	....	....	....	GR	....
	10% susp	......	....	......	....	....	....	SS	....	GR	....	....	....
$Ca(ClO)_2$ (Bleaching Powder)	filtered	SS, FZ, GR	....	SS, FZ, GR	....	FZ	....	S, GR, B, Sh, FZ	....	SS, FZ, Sh	....	GR, FZ	....
	5% susp	SS, FZ	....	SS, FZ	....	FZ	....	S, GR, B, Sh, FZ	....	SS, FZ	....	GR, FZ, SP	....
NaCl (Sodium Chloride)	10%	......	....	......	SS	....	....	SS, SB	SS, SB	....	....	....	....
	25%	......	....	......	SS	....	....	SS, SB, GR	SS, SB	....	....	....	....
$CaCl_2$ (Calcium Chloride)	10%	......	....	......	....	....	....	SS	....	....	....	....	....
	25%	......	....	......	....	....	....	SS	....	....	....	....	....
Turpentine		SS	....	SS	....	....	....	SS	....	....	....	....	....
Linseed Oil		SS	....	......	SS	....	....	SS	SS	....	....	....	....
Cottonseed Oil Fatty Acids		......	....	......	SS	....	....	SS	SS	....	....	....	....

(a) Effect of concentrated hydrochloric acid was recorded after only one week's exposure.

by heat before applying to the wood, or liquid preparations, so-called "acid-proof paints." Whether these preparations are successful in preventing the penetration of a liquid will depend upon the resistance of the coating to the action of the chemical and upon the completeness with which the pores of the wood are covered.

To test the resistance of the solid asphalts and pitches toward strong chemicals, fragments with sharp edges and projecting points, about the size of a peach-stone, were placed for one week in beakers containing acids and alkalis at room temperature. Any action of the liquid upon the material would then be revealed by a softening of the lump with consequent rounding of its edges, or by the liquid assuming a dark color.

In no instances was any softening noted, but the relative resistance of the different products could be judged by the colors imparted to the liquids.

50% and weaker solutions of H_2SO_4 had absolutely no effect upon the samples, but the concentrated acid soon became black and opaque.

About one-half of the samples were unacted upon by concentrated HCl, but some of the others imparted color to 25 and 50% HCl.

With one exception, 50% HNO_3 showed no effects upon the samples. The concentrated acid, however, in all cases colored deeply in less than one hour, and brown fumes of nitrous oxides were given off.

No action was noted with 25% NaOH or glacial acetic acid.

No pronounced difference in resistance between the asphalt and the pitches was apparent.

The efficiency of the liquid preparations was determined by applying them to the woods. Strips of redwood and oak were dipped into these and allowed to dry for 48 hours. A second dripping was then made and the strips allowed to dry for one week, after which they were weighed and calipered and then submerged in various acid and alkali solutions for a period of three weeks. Five samples were tested in this way and the results may be summarized as follows:

(1) The strips in all cases showed expansions and gains in weight, even when submerged in water. Even when the coating upon the wood seemed to be unblistered and in perfect condition, a cut with a pocket knife would show that the interior of the wood was more or less moist.

(2) Sometimes the paint would peel off or blister, especially in the more concentrated solutions, but in many instances the coating seemed to be entirely unacted upon, although the strip would be very soft, brittle, pliable or otherwise seriously affected.

(3) These coatings, however, retard the destructive action of the chemical upon the wood, since the expansions, contractions, and amounts absorbed after the three weeks immersion were always considerably less than those obtained upon the untreated wood after one week's soaking. Other effects such as brittleness, etc., were also less pronounced.

(4) The paints were quite efficient as a protection against 50% HCl and 25% H_2SO_4, but considerably less so against nitric acid and caustic soda. The asphaltic and the coal tar preparations seemed to be of equal value.

We may conclude, then, that although these products are quite resistant to chemical action it seems difficult to apply them as an absolutely impervious film upon the wood. They are penetrated even by water, but this penetration and its effects upon the wood are considerably retarded by the coating.

General Conclusions

(a) Wooden Tanks may be used for practically all of the common solutions used in chemical technology, in reasonable concentrations.

(b) Cypress, pine and fir are the woods which are least affected by common chemicals. Maple, oak and redwood are, for general purposes, of restricted adaptability.

(c) Nitric acid and caustic soda are the chemicals which have the most decided and most detrimental action upon wood.

(d) The so-called acid-proof paints will retard the action of the chemical upon the wood, but absolute protection should not be expected of them."

Exhaustive investigations were made during the past year to determine whether water, under pressure, would pass through cypress staves. Pieces from both old and new staves were placed between two metal flanges with appropriate gaskets between the wood surface and the steel. The two steel flanges were then bolted together so as to exert considerable pressure on the gaskets. Water was then forced through the center of the upper flange under a constant pressure of 65 pounds. The time of exposure to water pressure was from one hour to one week. In no case did any water appear on the lower flat surface of the stave samples. In other words there was no radial transmission of the water. In a good many instances drops of water appeared on the ends of the stave. The staves were split and it was shown that in every case the water traveled from a point where the pressure was applied longitudinally through the given annual ring and came out at the cross section. The point at which the water appeared on the cross section varied from close to the upper surface where the pressure was applied to close to the lower surface of the stave, depending upon the direction of the grain. In cases where the grain ran perfectly parallel to the upper surface, there was no water transmission.

In many instances, however, the grain was somewhat slanting and it was found that in cases where there was water appearance on the cross section, the water traveled through a very limited number of annual rings in a strictly longitudinal direction. The findings made as a result of this test are of course in entire accord with the behavior of the passage of liquids in tree trunks. MacDougal* has recently

*The Hydrostatic-Pneumatic System of Certain Trees. D. T. MacDougal, J. B. Overton, Gilbert M. Smith, Carnegie Institution of Washington, Publication No. 397, 1929.

published an exhaustive account of the transmission of liquids in tree trunks, from which it appears that the normal passage of liquids is from the root to the tip of the tree and that the transmission of liquids injected near the base of the tree trunk is in a strictly vertical direction upwards, from the point of insertion of the liquid. The liquid travels tangentially to a very limited extent but not at all radially. This experience is of course borne out by the fact that for centuries various species of wood, including cypress, have been used in the construction of tanks, vats, barrels, etc., for liquid containers and the only leakage that has ever been observed in practice has been through improperly constructed joints between staves or where obviously defective staves were used. It may therefore be said that with proper selection of cypress wood in the manufacture of tank stock, no leakage through the stave will take place.

The tests herein referred to were carried on with cypress originating all the way from South Carolina to Louisiana.

VIII. SEPARATORS FOR STORAGE BATTERIES

Cypress is one of the principal woods used for the manufacture of separators for storage batteries. These separators are thin plates usually made from knife-cut or sawn veneer in the form of long narrow sheets of the required width. If the veneer has been sawn tangentially to the annual rings of the tree, the separators are referred to as "rotary cut" while "sawn" separators are cut from quarters of the logs or radially to the rings. The latter are distinguished from the "rotary cut" separators by the grain of the wood which in this case appears as a series of bands parallel to the ribs.

The function of the separator is to keep the adjacent plates of the battery "separated and insulated from each other, as electrical contact between the two groups at any point will short-circuit the entire cell. For this reason separators are placed between the plates to prevent the circulation of electrolyte from plate to plate. Glass rods, perforated hard rubber and porous woods are principally used as separators."*

A clearer appreciation of the requirements for the effective separator will be essential to properly understand the adaptability of any material for such a purpose. The following quoted from "Storage Battery Manual," by Lieutenant Commander Lucius C. Dunn, for the use of the United States Navy, presents the salient points with reference to this question:

"By thus placing the plates closer together it will therefore be appreciated that for a proper functioning of the cell and in order to safeguard it against damage as a result of internal short circuits, it is necessary that the insulating medium or separators placed between the plates of the cell be of a high order of perfection. In addition to serving as an insulating medium, these separators must fulfill the following requirements:

"(a) They must be impervious to the action of the acid of the electrolyte.

"(b) They must be strong enough to withstand the mechanical chafing and compression incident to the normal expansion and contraction of the plates while working.

"(c) They must be unaffected by the temperatures attained by the cell during ordinary conditions of operating.

"(d) They must also contain no substances which have a deleterious effect upon any portion of the cell.

"(e) They must possess a fairly high degree of porosity in order to facilitate proper circulation and diffusion of the acid of the electrolyte into the plates during a discharge and, conversely, form paths for the return of the acid to the electrolyte on charge.

"(f) Although requiring a high degree of porosity, the individual pores of these separators should be so minute as to prevent as much as possible the entraining of gas bubbles therein, thus reducing the effects of polarization to a minimum."

Quoting further from this manual:

"Woods Used; Relative Life, Conductivity, Etc. Of the various woods which after receiving the proper treatment have been found suitable for storage battery separators and which are now more or less generally used, the following may be included:

(a) Basswood
(b) Poplar
(c) Douglas Fir
(d) California Redwood
(e) White Cedar
(f) Cypress

"The above list is given in the approximate relative order of life of each of the woods when operated under uniform conditions in the storage battery cell, considering the life of basswood as 100% the following table represents approximately the relative lives of the other woods when used as separators:

Wood	Life
Basswood	100 per cent
Poplar	100 per cent
Douglas fir	175 per cent
California Redwood	180 per cent
White cedar	190 per cent
Cypress	200 per cent

"It will be noted in the table that cypress is possessed of about double the life of either basswood or poplar; however it may be said that cypress, on account of its dense, close grain, has a higher factor of internal resistance, hence less conductivity, than basswood or poplar and for a given battery installation the voltage characteristic is not as good when using cypress as it is when basswood or poplar is used.

"Other things being equal, it may be said that the conductivity factor in woods used for separators varies inversely as the life, that is, the longer the life, the less the conductivity and vice versa.

"The subject of selection of woods for separators therefore resolves itself into choosing between life and conductivity and in making such selection the particular type and design of the battery as well as

*Storage Battery Engineering, by Lamar Lyndon.

the special services for which it is intended must necessarily be taken into consideration. In other words, if a battery is designed for very high discharge rates and the requirements of the service demand a high voltage characteristic even at the expense of life of the separator, then one of the soft woods such as basswood or poplar should be used. On the other hand, if long life and reliability against deterioration of separators with the consequent sacrifice of a certain amount of voltage characteristic is desired then one of the coniferous woods should be used. Furthermore it may be said that as a general policy, the coniferous woods as outlined in the above table are considered better suited to the requirements of the naval service than the softer woods, it is also believed that, with present stage of the art, the trend in commercial applications of storage batteries is in favor of the coniferous woods.

"With further reference to the general subject of selection of woods for separators, it should be stated that air-dried lumber produces better separators than kiln-dried stock, for the reason that the process of kiln-drying destroys a certain amount of the strength and endurance qualities of the wood, thus shortening its life, and air-dried lumber should therefore be used for this purpose when obtainable."

The effects which acid has upon separators has been much discussed particularly with reference to certain types of wood. A further quotation is of interest in this connection, same being taken from the volume entitled "Storage Batteries" by George Wood Vinal (U. S. Bur. of Standards, 1924).

"Classification of Material — For example, wood immersed in dilute sulphuric acid at 60°C to 100°C readily yields a considerable amount of acetic acid and the same result is obtained at lower temperature if an oxidizing agent, such as nitric acid, is also present. The amount of acetic acid that may be formed from the wood varies with the degree of hydration or oxidation of the material. The discussion of the chemistry of cellulose is beyond the scope of this book, but the reader is referred to the book by Cross and Bevan entitled 'Cellulose, and Outline of the Chemistry of the Structural Elements of Plants,' 1918.

"While it is known that acetic acid in appreciable quantities is harmful to a storage battery, it has been claimed by Skinner (note U. S. Patent No. 1,130,640, 1915) that a small quantity of acetic acid is beneficial rather than harmful to the negative plate. For reasons that are not fully understood, the presence of wood in the battery is beneficial and in some cases necessary for the continued functioning of the negative plates. This may be because of traces of acetic or similar acids extracted from the wood. The wood may be present as separators or be included in the active material of the negative plates. Patents covering the latter procedure have been issued to Chamberlain (note American 1,379,900, 1921) and to Willard (note British 155,944, 1919).

"Effect of Acid on the Wood—In judging the quality of wood separators, it is of importance to determine the effect of acid on the wood as well as to determine the electrical resistance. Sulphuric acid chars the wood as may readily be observed. The extent to which this action takes place depends very largely on the concentration and the temperature of the acid. When the specific gravity of the acid is 1.250 or below, the charring action is relatively slight, even when the wood is immersed for a long period of time. At 1.300 the charring action is noticeably greater and it becomes serious at concentrations higher than this. A series of experiments has been carried out at the Bureau of Standards (note Bureau of Standards Technologic Paper) to determine the decrease in strength of several kinds of wood as a result of being immersed in several concentrations of acid for a period of 21 weeks. Samples in the form of strips were cut from separators of different kinds of wood, all of which were of the same thickness and method of treatment. Each strip included two ribs and the web portion between. The samples were kept in the solutions at a constant temperature of 20°C (68°F) for the duration of the experiment and they were then taken out and subjected to tensile-strength tests while still wet. The results of this experiment are shown in Fig. 16. Each point is the mean of four determinations. A similar set of specimens were kept at 45°C (113°F). The breaking strengths for these averaged about half the values for the corresponding points at 20°C as shown in the figure. The effect of the acid in weakening the wood fiber is clearly shown in the falling of the curves."

The electrical resistance of separators is a significant factor and will of course have to be taken into consideration in determining the type of separators used. The following information developed by the U. S. Bureau of Standards is also quoted from George Wood Vinal's Volume entitled "Storage Batteries":

"Electrical Resistance — The resistance of individual separators, from the same lot and similarly treated, varied from 5 to 15%, but the accuracy of the measurements was probably good to about 1%. Several weeks' immersion in sulphuric-acid solutions is required prior to the measurements, in order that the resistance may reach a constant value.

"The resistance of the separators is expressed as the resistance per square inch or per square decimeter of surface. To apply the figures of Table VI to a particular case, it is necessary to estimate the area of the separators within the cell and to divide the figures which are given by this factor. For example if there are 100 square inches of separator surface, the resistance will be 1/100 of the value given for the particular kind of wood. Two values are given for redwood and cedar because of the different methods of cutting the samples. These indicate that the resistance of the sawn separators is somewhat less than that of rotary-cut separators of the same kind of wood.

"The porosity of the separators is an important factor in determining the physical performance of storage batteries since it affects not only the internal resistance but also the equalization of the acid concentrations during charge and discharge. The resistance of the separators depends on the length and

cross-section of the pores and indirectly on the direction of grain of the wood. As an approximation, it may be assumed that the porosity of the wood is inversely proportional to the resistance. No standard of porosity has been established for the determination of quality of the separators.

The figures given in Table 7 are for separators of the type used in starting and lighting batteries. The separators had 16 ribs and 17 slots. The thickness of the backweb was 0.052 inch; the thickness over the ribs, 0.085 inch; and the mean thickness 0.063 inch. All of these separators had received the same treatment."

Those interested in a further study of this problem are also referred to a recent paper of the U. S. Bureau of Standards entitled "Measurement of Electrical Resistance and Mechanical Strength of Storage-Battery Separators," by C. L. Snyder, Technologic paper of the Bureau of Standards, No. 271.

TABLE 7

Resistance of Storage Battery Separators

Each figure is the mean of observations on four samples of each kind. The separators were allowed to stand for 23 days in sulphuric acid of 1,280 sp. gr. before being measured. The resistances are expressed as the resistance per square inch of surface in the electrolyte of specific gravity 1.280 at 22°C.

Wood	Cut	Resistance in Ohms	
		Per Sq. Inch	Per dm^2
Poplar	Rotary	0.040	0.0026
Cherry	Rotary	0.042	0.0027
Basswood	Rotary	0.054	0.0035
Redwood	Rotary	0.084	0.0054
Redwood	Sawn	0.063	0.0041
Cedar	Rotary	0.084	0.0054
Cedar	Sawn	0.057	0.0037
Fir	Rotary	0.116	0.0075
Cypress	Rotary	0.124	0.0080

IX. HEAT INSULATING VALUE OF CYPRESS WOOD

CYPRESS is used for a good many purposes where the factor of heat conductivity is of significance. Cypress is particularly adapted on account of its decay resistance, ease of working, etc., to uses for fireless cookers, ice-cream tubs, vats, refrigerator rooms, incubators, etc. It is therefore of interest to know something of its heat conducting properties in comparison with other materials.

*"Wood conducts heat comparatively slowly. This is one of the principal properties that makes lumber desirable for building material, furniture, handles, refrigerators and fireless cookers. A wooden wall allows much less heat to pass through it than an iron, concrete, brick, or stone wall of the same thickness and under the same conditions.

"The rate at which heat passes through dry wood depends upon the direction of the fibers and upon the density. Wood conducts from two to three times as much heat along the fibers as across the fibers, other conditions being the same.

"Dense woods conduct heat more readily than light woods because in light woods a larger volume is occupied by air spaces, and air is a poorer conductor of heat than wood substance (cell walls). Therefore for fireless cookers, ice-cream containers, and other articles requiring good insulation, as light a wood as is practical should be used."*

Cypress is one of the lighter woods and its heat conductivity is correspondingly low, namely 0.00023. The following table* gives the heat conductivity of wood and various other materials at ordinary temperature.

Investigations are now in progress dealing with some of the details of heat conductivity by various species of wood. While these have not as yet progressed very far they already indicate the following:

First — Relation between moisture content and conductivity. It is of course recognized that the higher the moisture content of wood the greater its conductivity. Recent tests indicate that the amount of moisture present rather than the percentage present is the influential factor.

Second—Presence of knots. Indications are that the percentage of knots ordinarily present in lumber need hardly be given consideration in estimating its conductivity.

*The Properties and Uses of Wood, by Arthur Koehler, p. 67, 1924.

TABLE 8

*Heat Conductivity of Wood and Various Other Materials at Ordinary Temperatures**

Substance	Specific gravity	Number of calories of heat which pass from one face to the opposite face of 1 cubic centimeter of the material within 1 second of time when the difference in the temperature of the two faces is 1 degree Centigrade
Air		0.00006
Air cell, ½ inch thick		0.000154
Asbestos paper		0.00017
Mill board		0.00029
Concrete, cinder		0.00081
Concrete, stone		0.0022
Corkboard, pure		0.000106
Cotton, firmly packed		0.00010
Flaxlinum, vegetable fibers firm and flexible		0.000113
Glass, window		0.0025
Granite		0.0053
Hair felt		0.000085
Insulite		0.000102
Iron, wrought		0.144
Limestone and marble		0.0047 to 0.0056
Linofelt, vegetable fibers between layers of paper, soft and flexible		0.000103
Pulp board, stiff pasteboard		0.00015
Sand, white dry		0.00093
Sandstone, dry		0.0055
Sawdust		0.00012
Water		0.00136
Wood:		
Balsa	0.12	0.00012
Boxwood	0.90	0.00036
Cypress	0.46	0.00023
Fir, dry, across fiber		0.00009
Along fiber		0.00030
Greenheart	1.08	0.00112
Gum, red, across fiber (b)	0.50	0.00016
Along fiber (b)	0.50	0.00044
Lignum-vitae	1.16	0.00060
Mahogany	0.55	0.00031 to 0.00051
Maple, hard	0.71	0.00038
Pine, white	0.50	0.00027
Virginia	0.55	0.00033
Pine, across fiber (c)		0.00010
Along fiber (c)		0.00030
Oak	0.61	0.00035
Oak	0.65	0.00058
Poplar, yellow	0.58	0.00041
Wool, pure, loosely packed		0.00009

* From Smithsonian Physical Tables except (b) which are given as "satin walnut" by Barratt, T., "Thermal Conductivity," Proceedings Physical Society of London, vol. 27, 1914; and (c) which are taken from Duff's, A. W., "Textbook of Physics," 1910.

X. PAINTING OF WOOD

EXTENSIVE experiments by the Government and by independent paint experts have shown conclusively that cypress lends itself excellently to painting with the types of linseed oil paints commonly used for painting houses. Paint should be applied to cypress in exactly the same way that it is commonly applied to other soft woods. No special kinds of paint, no unusual proportioning of paint ingredients, no special paint thinners, and no departures from customary painting practices are required.

Until within comparatively recent times, most investigations dealing with painting centered around the chemical composition of the paint and very little, if any, attention was paid to the characteristics of the wood surface to which the paint was to be applied. Within recent years, many investigations have been carried out, in which the character of the wood surface has been considered just as much as the paint applied to the surface. Notable among these investigations were those initiated in 1924 by the U. S. Forest Products Laboratory. A large number of test fences were erected in various parts of the United States consisting of several thousand test panels. All commercial softwoods were included in these tests. Comparatively few paints were used in these tests because the influence of the paint composition on the durability of the paint coating is reasonably well understood from other tests. On this account, most of the panels in these tests were tested with two paints, white lead paste paint and a typical prepared paint, containing white lead, zinc oxide and asbestine. From the results of the use of these two paints and the existing knowledge of paint composition the behavior of most house paints can be evaluated.

WOOD PROPERTIES THAT AFFECT PAINT DURABILITY

All wood should be in the air dry condition before it is painted. Paint applied to green wood may blister and peel or, if that does not happen, the coating may crack in an objectionable manner known as alligatoring, which is due to insufficient drying of the priming coat. Moisture retards the drying of paint, especially so on cypress and redwood, which contain characteristic chemicals that impede oxidation of linseed oil. On dry cypress paint dries normally and the chemicals exert a favorable influence on the durability of the coating by hindering the ultimate oxidation of the oil that causes final paint failure.

Ordinarily the nature of the wood painted does not affect the behavior of the paint coating for at least a year or two after the paint has been applied. Ultimately the coating fails, of course, and it does so at an earlier age on some kinds of woods than on others.

F. L. Browne, in the U. S. Dept. Agriculture Leaflet No. 62 of September, 1930, entitled "Why Some Wood Surfaces Hold Paint Longer Than Others," has summarized the most important facts upon which the successful paint surface depends:

"The painting characteristics of a board depend primarily upon the amount and distribution of summer wood in it. Summer wood is the dense, horny, dark-colored portion of the annual growth ring, formed in the tree late in the growing season. It is made up of wood cells with very thick walls and small cavities and is in this sense much less porous than the spring wood, which is composed of cells with thin walls and correspondingly large cavities. Although liquids move more readily through the dense summer wood and paint oils are found to penetrate more deeply there, paint coatings do not seem to secure so firm an anchorage on summer wood as they do on spring wood; as a result, coatings exposed to normal conditions of weathering fail by flaking from the summer wood, leaving it bare while the spring wood remains apparently well covered. All native softwoods contain both summer wood and spring wood, but the proportions vary in different woods and in different boards of the same wood. There is in fact a greater variation in painting characteristics between the spring wood and summer wood in a single board than there is between average boards of different woods.

"The density or weight per unit volume of a softwood board measures roughly its ability to hold paint coatings because boards are heavy or light according as they contain much or little summer wood. However, if a board has many annual growth rings per inch, it may have the summer wood confined to narrow bands and yet be moderately heavy. Such boards hold paint far better than boards of equal weight cut from more rapidly grown trees, in which the summer wood is present necessarily in wide bands."

PAINT CHARACTERISTICS OF DIFFERENT SPECIES OF WOOD

The experiments of the Forest Products Laboratory, which is maintained by the U. S. Government at Madison, Wis., resulted in the following classification of softwoods by species:

Group 1 — Woods on which the paint remained intact and furnished adequate protection the longest.
- Cedar, Alaska.
- Cedar, Port Orford.
- Cedar, western red.
- Cypress, southern.
- Redwood.

Group 2 — Woods that the paint coatings failed to protect against weathering as long as they did the woods of group 1 even though the paint coatings remained intact about as long.
- Pine, northern white.
- Pine, western white.
- Pine, sugar.

Group 3	Woods from which the paint coatings flaked more rapidly than from the woods of groups 1 and 2 and which paint coatings failed to protect as long as they did the woods of group 1. Fir, white (and other *true* firs). Hemlock, eastern and western. Pine, western yellow. Spruce, eastern and sitka.
Group 4	Woods from which the paint coatings flaked most rapidly. Douglas fir. Larch, western. Pine, southern yellow.

The classification by species is somewhat of a rough approximation because there is a wide variation within most of the species in the painting characteristics of different types of boards. Thus the better types of boards sawn from woods in Group 4 paint as well as the poorer boards sawn from the woods in Group 3 and the better boards sawn from Group 3 woods are as satisfactory as the poorest one from Groups 1 or 2. The grouping by species gives the average results that may be expected from these species as they are customarily bought and used. If the better types of boards within a species are selected, the behavior of paint coatings on them may be more satisfactory than the average rating of the species.

Edge grain boards are decidedly better for painting than flat grain boards of the same species, particularly in the woods of Groups 3 and 4. Paint coatings remain intact longer on edge grain than on flat grain boards and edge grain boards require less adequate paint protection to keep them from weathering.

Flat grain boards paint better on the bark side than on the pith side. The bark and pith sides may be distinguished by the curve of the annual growth rings, seen on the end of the board. The rings are convex toward the bark side. If the grain of the wood becomes loose and shells up it almost always does this on the pith side and rarely on the bark side, which makes the pith side less desirable for painting than the bark side. This loosening of the grain on the pith side may cause early flaking of the paint coating. Raised grain is also more noticeable on the pith side than on the bark side.

Boards of high grade within any species, paint to better advantage than boards of low grade, for the reason that such defects as knots, pitch pockets, and pitch streaks prove difficult to handle. Over knots in the white and yellow pines, the paint coating often turns yellow and sloughs off leaving the knots exposed. Knots in cypress, the cedars, redwood, the true firs, the hemlocks, the spruces and larch, seldom cause the paint coating to turn yellow or slough off, but the knots are difficult to conceal and sometimes crack. Pitch pockets and pitch streaks often cause the paint coating to crack and mar its appearance by exuding resin. Pitch pockets should be chiseled out to remove all resinous substances and then be filled with putty.

When the factory or shop grades are used and the defects such as knots, pitch pockets, etc., are removed by remanufacture, it is natural that many paint troubles are also removed, but the fact remains that the clear wood remaining is often less desirable for painting than the wood contained in the select grades as these shop or factory grades come from that part of the log nearer the pith of the tree where the wood grew faster and where it is less uniform in texture.

The woods of Groups 1 and 2 are the softwoods of light weight, uniform texture or both. The woods of Group 4 are heavy and uneven in texture. The woods of Group 3 are either moderately heavy or uneven in texture. These two properties of wood, density and texture, afford an excellent means by which the painting characteristics may be judged. The reason for this is that early failure of the paint coating such as flaking, always begins over the bands of summer wood, particularly if they are wide, and the amount of summer wood determines the density of the wood.

SAPWOOD AND HEARTWOOD

Under ordinary circumstances, there is very little if any difference in the behavior of paint over sapwood and heartwood. If the unprotected surfaces of the boards come in contact with water for long periods, however, the paint may fail over the sapwood sooner than over the heartwood. In most types of construction such conditions can be avoided, but if water or continued moisture cannot be kept out, the heartwood of one of the durable species, such as cypress, should be used to prevent early decay of the wood.

CHARACTERISTICS OF DURABLE PAINT

Inasmuch as the authorities differ widely about the relative merits of the several kinds of house paints on the market, it is safe to say that each has its advantages and disadvantages as compared with the others and the choice between them must remain, to a large extent, a matter of personal opinion. Most experts will agree with the few general principals which follow.

The most durable paints are dark in color. Pure iron oxide red paint and black paint made with one of the carbon blacks are the most durable of all. The yellow, red and brown paints made with natural earth pigments in which the color is due chiefly to iron oxide, or paints made with artificial iron pigments are very durable, as are also paints made with chrome yellow, chrome green and prussian blue. Even the best white paints are much less durable than these deeply colored paints. Paints of light color made by tinting white paint with the deeply colored pigments are intermediate in durability.

White paints owe their whiteness and opacity to one or more of the following opaque pigments: basic carbonate white lead, basic sulphate white lead, zinc oxide, leaded zinc oxide, titanox, or lithopone.

Besides these white and the colored pigments, many paints contain so-called inert pigments which lack opacity. Common inert pigments are: asbestine (magnesium silicate), silicia, barytes blanc fixe (barium sulfate), china clay (kaolin) and whiting. Moderate amounts of inert pigments often serve useful purposes in paints, but white or light colored paints containing large amounts of them are cheap paints and are either deficient in opacity or else limited in the amount of surface that a gallon of paint will cover. In paint, as in lumber, the price paid may be indicative of the service which will be rendered.

The liquid in a good house paint is at least four-fifths pure linseed oil. It contains at most only a trace of water and no varnish, except that black, dark blue, or dark green paint may contain some good varnish. The following rules will serve as a rough guide in choosing paints for quality, assuming that the paints compared are of the same color and reduced to proper consistency for application of a final coat.

1. Choose the paint containing the highest proportion of pigment to liquid, if possible determining the proportions by volume because the proportion by weight is somewhat less reliable.

2. If they are white or tinted paints choose the one containing the highest proportion of opaque white pigments. If a deeply colored paint, choose the one containing the highest proportion of iron oxide, carbon black, chrome yellow, chrome green or prussian blue.

White lead is the oldest of the opaque white pigments and is the only one commonly used without mixing with other opaque white pigments. Straight white lead paint chalks deeply and sloughs from summer wood in very small flakes. If repainting is deferred until much summer wood is left bare white lead paint leaves a surface more easily covered smoothly with new paint than other pigment mixtures. Paints containing zinc oxide and white lead usually do not chalk as deeply, fade less in color, and may not become as badly soiled with dirt. If repainted before there is much flaking from summer wood they offer a less absorptive surface on which a smooth glossy coating can be restored with a single coating instead of two coats, but if repainting is deferred until much summer wood is bare, such paints leave a rougher surface because the flakes of coating that fall off are larger. In extreme cases, the old coating may have to be removed before repainting. Paints containing titanox and zinc oxide in suitable proportions are very opaque, chalk superficially, hold their color well, and remain relatively free from dirt. Lithopone is cheaper than the other opaque pigments and, in combination with zinc oxide and inert pigments, can be made into very serviceable paint.

In localities where the climate is ordinarily very dry for at least a part of the year, straight white lead paint is more durable than mixtures of white lead and zinc oxide. In humid southern climates such as the south Atlantic and Gulf Coasts, mixtures of zinc oxide and white lead outlast straight white lead paint. In moderate climates like New England and the middle Atlantic states, all paints are more durable and there is little difference in durability between straight white lead and mixtures of white lead and zinc oxide, provided that the amount of zinc oxide is not more than half that of the white lead by weight.

Paints are sold in the form of paste, semi-paste or prepared paints. Prepared paints contain the proper amounts of liquids and drier for application as finish coats and are sold in white and many colors. Paste and semi-paste paints are usually white or one of the deep colors and must be reduced with linseed oil, volatile thinner and often some drier added before they are ready to apply. To make paint of light color, some of the deeply colored paints must be thinned and added to the white base paint in suitable amounts and colors. Paste and semi-paste paints have the important advantage over prepared paints in that the painter can alter the proportions of pigment, oil, and thinner over wider limits and is therefore able to mix priming coat and body coat paints that are not easily obtainable with prepared paint.

RECOMMENDED PRACTICES FOR PAINTING WOOD

Lumber for exterior construction should be in an air dry condition before it is delivered on the job. After receipt, it should be so handled that it will remain in that condition until used. Lumber piles should be raised above the ground, providing ventilation underneath and the piles should be kept covered as protection from rain. Exterior lumber should not be stored in a heated building where it may become too dry. After erection, dressed lumber should be painted promptly. The best moisture content of lumber for painting is roughly from 12 to 18 per cent. If the surface of the lumber becomes wet with rain or otherwise, it should be allowed to dry before painting.

Standard practice calls for three coats of paint on new wood surfaces.

Paint purchased in the form of semi-paste should be mixed according to the following formulas:

	First Coat	*Second Coat*	*Third Coat*
Semi-paste paint, gallons	1	1	1
Raw linseed oil, quarts.	4	1	2¾
Turpentine, quarts	2½	1⅗	⅙
Paint drier, pints......	⅓	⅓	⅓

Boiled linseed oil may be used instead of raw linseed oil, in which case only half the indicated amount of drier should be added. If the semi-paste paint already contains the drier, use raw linseed oil and do not add any more drier. White lead paste paint is sold by weight instead of by volume and in the forms of soft paste (semi-paste) and of heavy paste, which contains less oil. One gallon of soft paste white lead weighs 30.8 pounds and should be mixed with the amounts of liquids given in the formulas. To mix heavy paste white lead, take 28.4 pounds, add 1¼ quarts of raw linseed oil, and then add the liquids given in the formulas.

To make tinted paints starting with white paste paints, mix white paint according to these formulas, then thin the necessary kinds of deeply colored pigment pastes (colors ground in oil) with a little turpentine and add them to the white paint in the required amounts to give the desired color. Ordinarily only a small amount of colored pigment is necessary.

New woodwork is sometimes painted with two instead of three coats. When skilfully done, satisfactory results may be obtained, but the practice is not generally recommended. Thicker coats must be applied and therefore the mixtures should be made as follows:

	First Coat	*Second Coat*
Semi-paste paint, gallons	1	1
Raw linseed oil, quarts	2	2½
Turpentine, quarts	1¼	⅛
Paint drier, pints	⅓	⅓

If prepared paint is purchased, three coats should always be applied to new woodwork because prepared paint is designed for such use. For the priming coat, 2 pints of linseed oil and 1 pint of turpentine should be added to a gallon of prepared paint. For second coat add 1 pint of turpentine to a gallon of paint. The paint is already correctly mixed for third coat.

Repainting should be done before flaking of the old coating from summerwood goes very far and before wood checking due to insufficient protection has advanced to any great extent. When repainting is done at the proper time, one coat is often all that is necessary and, if the old paint contained zinc oxide, one coat is often all that is desirable. It should be mixed according to the instructions already given for third coat paint on new woodwork. When the old coating is very absorptive or when repainting has been deferred until there is much bare summerwood, two coats are needed which may be mixed as follows:

	First Coat	*Second Coat*
Semi-paste paint, gallons	1	1
Raw linseed oil, quarts	1½	2¾
Turpentine, quarts	2½	⅛
Paint drier, pints	⅓	⅓

The foregoing formulas are suitable for painting all softwoods. Recommendations are often made to use special thinners in place of turpentine or to change the proportions of oil and turpentine greatly in mixing the priming coat for some woods. Investigations at the Forest Products Laboratory prove that such alterations do not improve and, if carried too far, impair the durability of paint coatings.

SOME REASONS FOR SO-CALLED PAINT FAILURES

A choice of those species that take and hold paint better will overcome some of the difficulties of paint failure, but the conditions governing the use of lumber and paint are more responsible for unreasonably early failures of the paint to either protect or continuously beautify, than are the materials themselves. Probably the chief cause of early paint failure is moisture. More than any one thing and probably any combination of other causes excessive moisture either on or in the wood to be painted, or moisture coming from within the house, or from poorly drained surroundings, causes the greatest number of so-called paint failures.

Moisture within a house will seek an outlet when humidity of the outside air is lower than inside. This moisture, if allowed to find its way out through the side walls, will certainly cause trouble for the outside paint. The paint may peel, blister or in other ways destroy the continuity of the paint coating.

This moisture may be present in the house from natural continuous sources or may be caused by attempts to quickly dry out the plaster in newly constructed houses, thus driving the moisture through the outside walls.

The basement may contain moisture which comes in through poorly built walls or floors. It need not be visible to the eye, but if moisture stands in the soil around or under the walls or floor of a poorly constructed basement, this moisture will surely find its way upward and be absorbed by the various materials used in the house construction and later be given off through the walls causing trouble to the outside paint.

After a survey of some 1,500 houses of all types by a competent authority, a very substantial percentage of paint failures was traced to these sources and could have been prevented by proper caution. The various causes of paint troubles on the outside of house walls all deal with excessive moisture from one source or another, except where the paint itself is at fault and this latter condition is more rare than is usually considered.

It is only necessary to adopt such type of construction as will prevent moisture from getting into the basement and also provide proper ventilation of the side walls and attic to allow of the passage of this moisture to the outside air, by other means than through the walls. If during construction and the drying out of the plaster, sufficient time and ventilation is provided, very little trouble, if any, will develop on the outside painted walls.

Some of the modern types of house construction bring about tighter and tighter wall construction, thus blocking up all air passages through which moisture might find an outlet to the attic and escape through the wooden shingles, if the house is fortunate enough to have this time-proved roof covering.

The present emphasis on the value of insulating materials to prevent heat losses brings about a type of construction that leaves few, if any, channels through which moisture can easily find an outlet and it must therefore be absorbed by the walls and thus pass to the outside air, either through the paint or by pushing the paint off to form an opening.

Circular No. 317, October, 1927, of the American Paint and Varnish Manufacturers Association, by Henry A. Gardner, entitled "Painting Defects on Wood Surfaces, Their Cause and Cure," lists most causes of paint failures both from moisture and from improper application of the paint. A study of this pamphlet is recommended.

SUMMARY

The foregoing deals with fundamental facts relating to the painting of wood surfaces. All of it applies to the painting of cypress. Careful attention to the principles discussed will result in successful painting. Good construction, durable paint, and skilful craftsmanship in application are most economical in the long run. Nowhere will the original investment pay better than in the painting of wood surfaces.

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